WATER QUALITY CHARACTERISTICS OF LAKE SIMCOE 1980

March 1982

Ministry of the Environment
Ontario

WATER QUALITY
CHARACTERISTICS
OF
LAKE SIMCOE
1980

Chapter 1 - Prepared by:
J.E. Dobson
R. Shaw
Technical Support Section
Central Region

Chapter 2 - Prepared by:
K.H. Nicholls
Limnology Section
Water Resources Branch

Chapter 3 - Prepared by:
M.B. Jackson
Limnology Section
Water Resources Branch

March 1982

© 1982, Her Majesty the Queen in Right of Ontario. For permission to republish, contact W. Lammers, Ministry of the Environment, Suite 700, 150 Ferrand Drive, Don Mills, M3C 3C3

TABLE OF CONTENTS

	Page
LIST OF FIGURES	
LIST OF TABLES	
INTRODUCTION	1
SUMMARY	4
CHAPTER ONE - 1980 MONITORING PROGRAM	
1.1 Station Listing & Description	6
1.2 Survey Procedure	7
SURVEY RESULTS	
1.3 Temperature	8
1.4 Dissolved Oyxgen	14
1.5 Water Chemistry Characteristics	17
1.6 Nutrients	20
(a) Phosphorus	20
(b) Nitrogen	34
1.7 Water Clarity & Chlorophyll *a*	40
CHAPTER TWO - THE PHYTOPLANKTON OF LAKE SIMCOE, 1980	
2.1 Abstract	46
2.2 Introduction	47
2.3 Methods	48
2.4 Results and Discussion	48
(a) Composition	48
(b) Trophic Status	56
References	64
CHAPTER THREE - *CLADOPHORA*, NUTRIENTS AND HEAVY METALS IN NEARSHORE LAKE SIMCOE, 1976 AND 1980	
3.1 Abstract	67
3.2 Introduction	68
3.3 Materials and Methods	69
3.4 Results	69
(a) *Cladophora* Growth	69
(i) Periodicity	69
(ii) Controlling Factors	74
(b) Nutrients and Heavy Metals	81
(i) Phosphorus and Nitrogen	81
(ii) Mercury and Lead	89
3.5 Discussion	89
3.6 Summary	94
3.7 Acknowledgments	95
References	96

LIST OF FIGURES

		Page
Figure 1:	Sampling Station Locations, Lake Simcoe, 1980	2
Figure 2:	Dissolved Oyxgen & Temperature Profiles at Station K45, Lake Simcoe, 1980	11
Figure 3:	Water Temperatures, 1.0 meters above Bottom at Station K39, K42, K45, Lake Simcoe, 1980 and P1, Picard Lake 1978	12
Figure 4:	Optimal Conditions for Lake Trout, Lake Simcoe, K45, 1980	16
Figure 5:	Temperature & Dissolved Oyxgen Profiles at Station C6, Lake Simcoe over the 1980 Sampling Period	18
Figure 6:	Mean Total Phosphorus Concentrations in the Euphotic Zone of Lake Simcoe, 1980	21
Figure 7:	Mean Dissolved Reactive Phosphorus Concentrations in the Euphotic Zone of Lake Simcoe, 1980	22
Figure 8:	Euphotic Zone Total Phosphorus Concentrations at Stations C1, C6, C9 in Cook Bay and Total Phosphorus Concentrations in the Holland River, 1980	24
Figure 9:	Euophotic Zone Phosphorus Concentrations at Stations K39 and K42, 1980	28
Figure 10:	Phosphorus and Dissolved Oxygen Concentrations at 1 m. off the bottom, K39, 1980	30
Figure 11:	Phosphorus and Dissolved Oxygen Concentrations at 1 m. off the bottom, K42, 1980	31
Figure 12a:	Euphotic Zone Phosphorus Concentrations at Station K45, 1980	33
Figure 12b:	Phosphorus & Dissolved Oxygen Concentrations at 1 m. off the bottom, K45, 1980	33
Figure 13:	Mean Total Kjeldahl Nitrogen Concentrations in the Euphotic Zone of Lake Simcoe, 1980	35
Figure 14:	Mean Ammonia Concentrations in the Euphotic Zone of Lake Simcoe, 1980	37
Figure 15:	Inorganic Nitrogen Concentrations Measured 1 m. above the bottom at Station K42, 1980	38

Figure 16:	Mean Nitrate Nitrogen Concentrations in the Euphotic Zone of Lake Simcoe, 1980	39
Figure 17:	Mean Secchi Disc Measurements at Nine Sampling Stations, Lake Simcoe, 1980	41
Figure 18:	Mean Summer Chlorophyll a Concentrations at Nine Sampling Stations, Lake Simcoe, 1980	43
Figure 19:	Seasonal distribution of class densities at Stations K45 and E51.	50
Figure 20:	Seasonal distribution of class densities at Stations C6 and n31.	51
Figure 21:	Seasonal distribution of class densities at Station K39.	52
Figure 22:	The relationship between the average biomass of total phytoplankton (May-Oct.) and the number of genera of Chlorophyceae at the nine Lake Simcoe stations and three additional locations; Holland River; Bay of Quinte; Station B; Georgian Bay, Cape Rich area of Georgian Bay.	52
Figure 23:	Primary matrix of average class densities at the nine Lake Simcoe stations, May 20 - Sept. 23, 1980 and percentage of total phytoplankton biomass.	54
Figure 24:	Matrix and dendrogram of percentage similarities of average class density at the nine Lake Simcoe stations May 20 - Sept. 23, 1980.	55
Figure 25:	Relationship between average May-Oct. biomass of Scenedesmus sp. and total phytoplankton biomass at the nine Lake Simcoe stations.	57
Figure 26:	Relationships between average phytoplankton biomass and average total P, total N, total N-to-Total-P ratios and Secchi disc visibilities at the nine Lake Simcoe stations, May 20 - Sept. 23, 1980.	59
Figure 27:	Regression of average (May-Oct.) phytoplankton biomass on total phosphorus and Secchi disc reciprocal on total phytoplankton biomass in the Kawarthat-Trent-Qunite System showing the 95% confidence interval for predication of "Y" and "X".	60
Figure 28:	Nearshore sites in Lake Simcoe, 1976 and 1980.	70
Figure 29:	Cladophora standing crop, temperature and internal total phosphorus and nitrogen and N:P ratios at KI in Lake Simcoe, 1976.	75

Figure 30:	Internal N:P ratios at KI, OR and IN in Lake Simcoe, 1976.	77
Figure 31:	Mean external and internal phosphorus and nitrogen parameters at the west nearshore sites in Lake Simcoe, June through November, 1976.	82
Figure 32:	Mean external and internal phosphorus and nitrogen parameters at the east nearshore sites in Lake Simcoe, August through October, 1976.	83
Figure 33:	Mean external and internal phosphorus and nitrogen parameters in Lake Simcoe, May through October, 1980.	84
Figure 34:	Discriminant scores of 'affected' and 'remote' nearshore sites in Lake Simcoe, 1976 and 1980.	87
Figure 35:	Mean internal total mercury and lead concentrations at nearshore sites in Lake Simcoe, 1980.	90

LIST OF TABLES

		Page
Table 1:	Comparative Surface Area, Maximum Depth and Temperature Data	9
Table 2:	Mean Total Phosphorus, Mean Dissolved Reactive Phosphorus and Percentage Dissolved Reactive Phosphorus of Total Phosphorus for the Euphotic Waters in Cook Bay and the Holland River, 1980	25
Table 3:	Mean Secchi Disc Reading and Chlorophyll a Concentration for Stations K39, K42 and K45, 1975-1980.	44
Table 4:	Average total phytoplankton biomasses (mm^3/L) at the nine Lake Simcoe stations May 20 - Sept. 23, 1980 and divided into first half (May 23-July 21) and second half (July 21-Sept. 23) time periods.	49
Table 5:	Morphometric data for Cook Bay and its drainage basin and estimates of May to October total phosphorus loading.	62
Table 6:	Nearshore site descriptions in Lake Simcoe, 1976 and 1980.	71
Table 7:	Cladophora standing crop at 0.5 m and 1.0 m depths at KI in Lake Simcoe, 1976.	72
Table 8:	Matrix of simple correlation coefficients between Cladophora standing crop at 0.5 m depth, temperature, internal total phosphorus, nitrogen and nitrogen to phosphorus ratio at KI in Lake Simcoe, June 16 through September 17, 1976.	76
Table 9:	Results of stepwise multiple regression analysis between Cladophora standing crop at 0.5 m depth and significant independent variables, temperature, and internal nitrogen to phosphorus ratio at KI in Lake Simcoe, June 16 through Sept. 17, 1976.	78
Table 10:	Summary statistics of external concentrations of total phosphorus and soluble reactive phosphorus, total inorganic nitrogen, and total Kjeldahl nitrogen at nearshore sites in Lake Simcoe, 1976 and 1980.	79
Table 11:	Summary statistics of internal total phosphorus, nitrogen, and nitrogen to phosphorus ratio in Cladophora at nearshore sites in Lake Simcoe, 1976 and 1980.	80
Table 12:	Results of direct discriminant analysis between 'affected' and remote sites in Lake Simcoe, 1976 and 1980.	86
Table 13:	Summary statistics of internal total mercury and lead in Cladophora at nearshore sites in Lake Simcoe, 1980.	88

INTRODUCTION

The Ministry of the Environment and formerly the Ontario Water Resources Commission have conducted numerous studies of Lake Simcoe commencing in 1970. Ministry of the Environment reports published to date include:

1. A Preliminary Report on Water Quality Characteristics of Kempenfelt Bay and Adjacent Lake Simcoe, 1970.

2. Aquatic Weed Growths in Lake Simcoe, 1971.

3. Lake Simcoe Basin: A Water Quality and Use Study, June, 1975.

4. Mercury in the Lake Simcoe Aquatic Environment, September, 1978.

The Central Region of the Ministry of the Environment has monitored the water quality of Lake Simcoe since 1975. Between 1975 and 1979 three open water stations were sampled (K39, K42 and K45). In 1980, the program was altered and expanded. The three initial stations continued to be monitored plus an additional six lake stations and a station on the Holland River (Figure 1).

The number of stations was increased in order to better assess the effectiveness of the measures suggested by the Cabinet Committee for Resource Development, and adopted by this Ministry. These measures are directed to improving the water quality of Lake Simcoe and thus affording more opportunity for an enhanced fishery. The specific recommendations were aimed at reducing the yearly phosphorus loading to a lake from its projected 1983 level of 105 tonnes to 87 tonnes. It was suggested this be accomplished by:

1. Removal of the sewage from the municipalities of Aurora, and Newmarket from the Lake Simcoe Basin to the York-Durham sewage scheme.

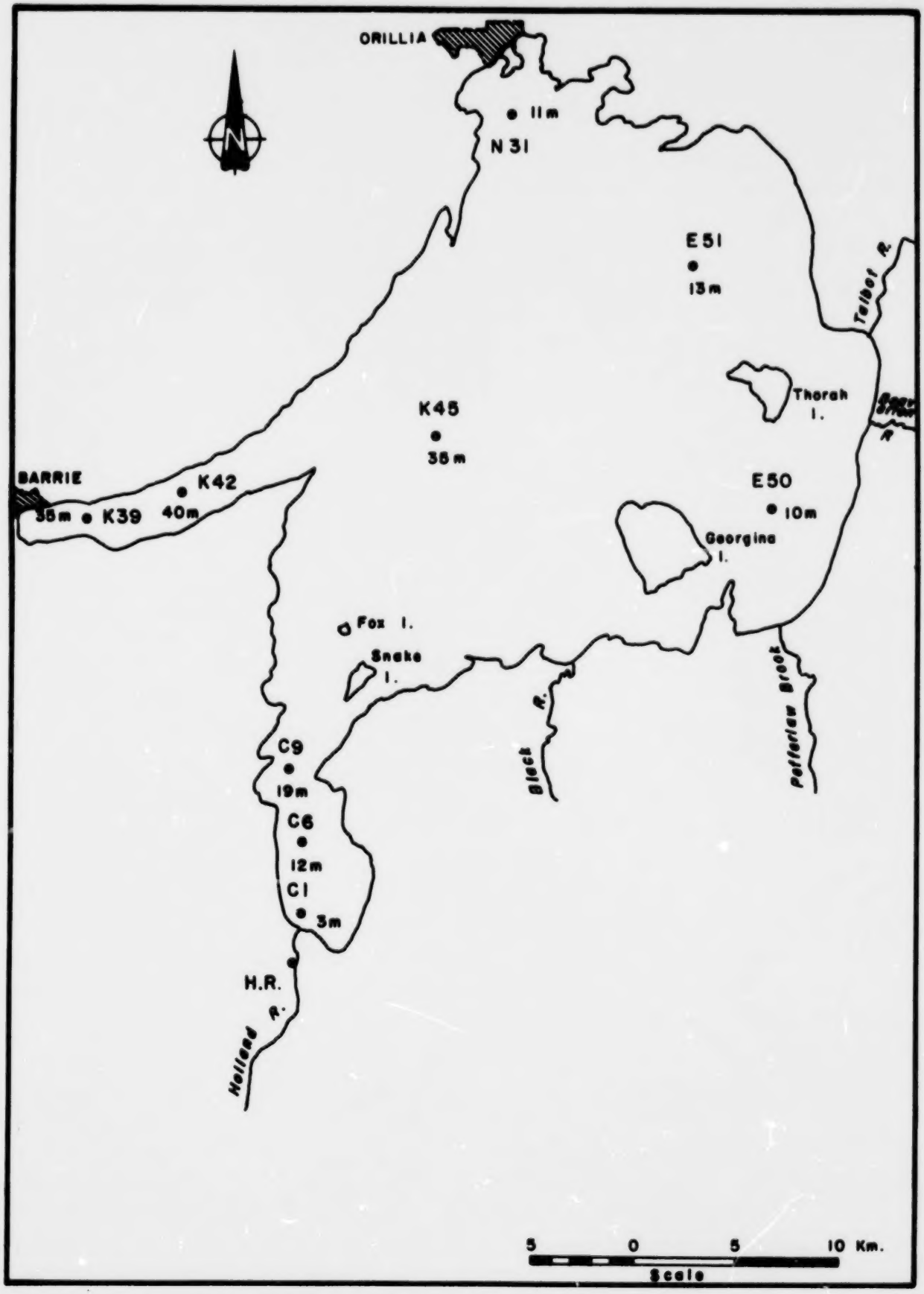


Figure 1 : Sampling Station Locations - Lake Simcoe, 1980.

2. Reduction of the effluent phosphorus concentration at the Barrie and Orillia sewage treatment facilities from the present requirement of 1 mg/L to 0.3 mg/L.

3. Reduction of the phosphorus loading from the Holland Marsh and non-point source inputs associated with agricultural activities within the basin.

This report summarizes the data collected during 1980.

SUMMARY

Lake Simcoe is the largest in-land lake in Southern Ontario. Due to its proximity to Metropolitan Toronto, Lake Simcoe supports a major area for recreation. Open lake phytoplankton and water quality parameters have been monitored since the early 1970's. The number and location of the stations varied depending upon the extent and purpose of the study. In 1980, a maximum of 11 open lake stations were sampled. Nearshore water quality and Cladophora growth characteristics were monitored in1976 and 1980, only.

The various water quality monitoring programs conducted on Lake Simcoe since 1975, indicate that in general, the water quality in Lake Simcoe is satisfactory. The highest nutrient levels in 1980 were found near highly populated areas such as the south end of Cook Bay and west end of Kempenfelt Bay. Phosphorus concentrations in the Holland River doubled those found in Cook Bay. There was a noted phosphorus build-up in the bottom waters of Kempenfelt Bay, the deeper water stations. Concentrations of nitrogen were similar to phosphorus with the highest build-up levels in Cook and Kempenfelt Bays. By late August, there was a substantial increase in ammonia concentrations in the bottom waters of the two deep water stations in Kempenfelt Bay and the other deep station at the mid-lake.

Due to the expansive surface area of the lake, and being subject to high wave action and extensive vertical mixing, therefore resulted in Lake Simcoe seldom having a well-defined thermocline. The water column typically represented a thermal transition. In comparision to other lakes of the same depth, the bottom water temperatures were quite high (8-9°C). Dissolved oxygen levels remained at or near 100% saturation throughout the sampling season. Typical clinograde curves (decreasing oxygen levels with increasing depths) were noted at the deeper stations. The severity of the curves increased with time throughout the summer. The bottom waters at spring turnover were 100% saturated decreasing to 15 to 20% preceeding fall turnover. The shallower stations showed little decrease in dissolved oxygen with depth. From mid-August until fall overturn, optimum conditions for lake trout were non-existent, based on temperature and O_2 concentrations.

Conductivity being a measure of the water's ability to conduct an electrical current due to the presence of dissolved salts, showed little horizontal variation across the lake. The average conductivity measurement was 332 umhos/cm^2 for the lake. The mean conductivity measurement in the Holland River almost doubled this value.

Mean measurements of iron and silica were higher in the Holland River (iron - .5 ug/L, silica - 1.6 mg/L) than found throughout the lake (iron - .50 ug/L, silica - .67 mg/L).

Lake clarity was measured using a Secchi disc. The average Secchi disc reading for the open lake was 4.4 metres, characteristic of moderately clear waters. More turbid waters were encountered in lower Cook Bay (average 2.9 m). Generally, Secchi disc measurements increased during the sampling season, peaking at mid-summer.

Algae levels as measured by chlorophyll a concentrations were generally fairly low throughout the lake (less than or equal to 3.0 ug/L) over the sampling period. Maximum chlorophyll a concentrations were recorded in the early spring (May-June) and late fall (October). Concentrations were generally higher in Cook and Kempenfelt Bays.

Insufficient on-shore wave action appears to be the primary physical factor limiting the growth of Cladophora in Lake Simcoe. The exposed and nutrient-enriched cobblestone beach just east of the Orillia Sewage Treatment Plant outfall is the only known location which supports problem growths of Cladophora. Trends in internal and external concentrations of nutrients and internal concentrations of heavy metals at the nearshore sites were similar to those found in proximity to the open lake stations. Kempenfelt and Cook Bays tended to have the highest concentrations.

The phytoplankton biomass and species composition demonstrated a clear gradient in trophic status through Lake Simcoe ranging from most enriched in southern Cook Bay to least enriched in the open waters of the main lake.

1980 MONITORING PROGRAM

1.1 Station Listing & Description

The sampling stations and their locations are as follows:

1) K39; located in Kempenfelt Bay, mid-way between Minet Point and Deep Point. Maximum water depth - 35 metres.

2) K42; in Kempenfelt Bay, mid-way between Shanty Bay and Bear Point. Maximum water depth - 40 metres.

3) K45; in the main body of the lake, 6.5 kilometres northeast of Oro Beach. Maximum water depth - 3 metres.

4) E50; on the east side of the lake off McCrae shoal, between Cedarhurst Beach and Beaverton. Maximum water depth - 10 metres.

5) E51; northwest of Thorah Island at the marker buoy. Maximum water depth - 13 metres.

6) N31; at the north end of the lake mid-way between Grape Island and Four Mile Point. Maximum water depth - 11 metres.

7) C9; in Cook Bay, east of the Cook Bay Shoal. Water depth - 19.0 metres.

8) C6; in Cook Bay mid-way between De Grassi Point and Orchard Beach. Maximum water depth - 12 metres.

9) C1; at the mouth of the Holland River mid-way between the two channel markers. Maximum water depth - 3 metres.

10) HR1; in the Holland River at channel marker number T222.

1.2 Survey Procedure

Sampling was carried out approximately once every three weeks at the above-mentioned stations, commencing at ice-out and continuing until fall turnover. The number of visits to each station was dependent on weather conditions and time of turnover at the individual station. Each station was sampled a minimum of eight times during the open water period of 1980.

During each visit to the lake stations, the following samples and measurements were obtained. This procedure was modified at some of the stations due to the limited depth of the water column.

1) Secchi disc reading.

2) Samples for the following analyses and determinations were collected as euphotic zone composites. The euphotic zone was defined as 2½ times the Secchi disc reading:

   a) chlorophyll _a_, _b_ and acidified chlorophyll _a_ analyses;

   b) phytoplankton cell volume determination;

   c) total phosphorus, dissolved reactive phosphorus, free ammonia, nitrite, nitrate, and total kjeldahl nitrogen, iron, silica and conductivity analysis.

3) Water samples were obtained using a Van Dorn sampler from 1, 5, 10 and 15 metres above the bottom. These samples were analyzed for the same parameters listed in (2)(c), as was the Holland River sample, which was obtained as a grab sample.

4) Temperature and dissolved oxygen profiles at 1 metre intervals using either a YSI metre or a Hydrolab Digital Model No. 4041 which was calibrated prior to each run using the Azide modification of the Winkler method. To verify the dissolved

oxygen readings, samples were taken at a depth of 1 metre and 1, 5, 10 and 15 metres above the bottom. The dissolved oxygen concentration of these samples was determined using the Azide modification of the Winkler method.

All chemical analyses were performed at the Ministry of the Environment Laboratory in Rexdale. The following is a discussion of selected data collected during the 1980 survey.

The chemical data collected during this survey are available on microfiche, a copy of which may be obtained from the M.O.E., Central Region, 150 Ferrand Drive, Don Mills, M3C 3C3.

Survey Results

1.3 Temperature

Lake Simcoe, which is the largest inland lake in the Central Region, has a very broad surface area relative to its depth (Table 1). The water column is subject to high wave action and therefore extensive vertical mixing. Thus, the thermal input into the lake is considerably greater than encountered in lakes of similar depths but smaller surface area. The resultant pattern of thermal stratification through the ice-free period is less pronounced. Stratification takes longer to form than typically encountered in dimictic lakes, resulting in Lake Simcoe seldom having a well-defined thermocline. Usually there is a gradual decrease in temperature from top to bottom with one or two minor thermoclines.

Based on common characteristics, the sampling stations have been divided into three groups for discussion purposes; Group 1 consisting of K39, K42 and K45; Group 2 consisting of E50, E51, N31 and C6; Group 3 consisting of C9 (Figure 1). Station C1 has not been included in this discussion due to the shallow depth of the water column at this location.

Table 1: Comparative Surface Area, Maximum Depth & Temperature Data

Lakes/ Station	Surface Area (km^2)	Maximum Depth (m)	Maximum Surface Temp. (°C)	Maximum Bottom Temp. (°C)*
Simcoe; K39	725.0	35	20.8 (13/8/80)	10.8 (16/10/80)
Simcoe; K42		40	22.1 (12/8/80)	10.4 (16/10/80)
Simcoe; K45		33	21.5 (13/8/80)	11.0 (22/10/80)
Vernon; V1 (Muskoka County)	14.44	30	23.0 (16/8/78)	5.0 (9/10/78)
Bella; B1 (Muskoka County)	3.38	36	22.0 (8/8/78)	4.5 (31/8/78)
Picard; P1 (Peterborough County)	0.75	34	25.0 (15/7/79)	5.1 (15/8/79)

* Measured 1.0 m. above the bottom

Group 1 is comprised of the three deep water stations (K39, K42, K45). Incomplete thermal stratification was found at these stations prior to June 3, 1980. The profiles, at the three stations on this date exhibited a step-like decrease with depth. This condition persisted until the August 13th sampling run, by which time the water columns had become weakly stratified. On subsequent sampling dates, the metalimnion became more distinct and by September 2, 1980, the temperature profile exhibited sharply defined thermoclines. Up to this date, typical profiles were much less distinct showing more of a thermal transition through a depth change of 10 to 15 metres.

When distinct thermal layers were present (mid-August), the metalimnion commenced at depths of 5 metres (K39), 7 metres (K42), and 10 metres (K45). During subsequent visits, the depths at which the metalimnion commenced, gradually moved downward corresponding to the overall mixing and cooling of the lake, until on October 22, 1980, (K45) (Figure 2) and October 30, 1980 (K39 and K42) complete mixing had occurred at the three stations.

Throughout the sampling period, thermal stratification appeared to be less defined in Kempenfelt Bay (K39 and K42) than at the mid-lake station (K45). This may be due to the fact that the axis of Kempenfelt Bay lies roughly parallel to the prevailing westerly winds, resulting in greater wind induced mixing than is prevalent in the open lake.

The hypolimnetic waters warmed continuously throughout the spring and summer indicating considerable heat transfer through the water column, and therefore some degree of physical mixing. Following spring breakup, the water column at these stations was generally near the temperature of maximum density, 4°C. As the summer progressed, bottom water temperatures* rose rapidly, stabilizing between 8 and 9 °C by July 3, 1980, (Figure 3). The bottom water temperatures were much higher than is typically expected in lakes of similar depths. Table 1 summarizes the maximum surface and bottom water temperature for the water column at

* measured 1.0 metres above the bottom.

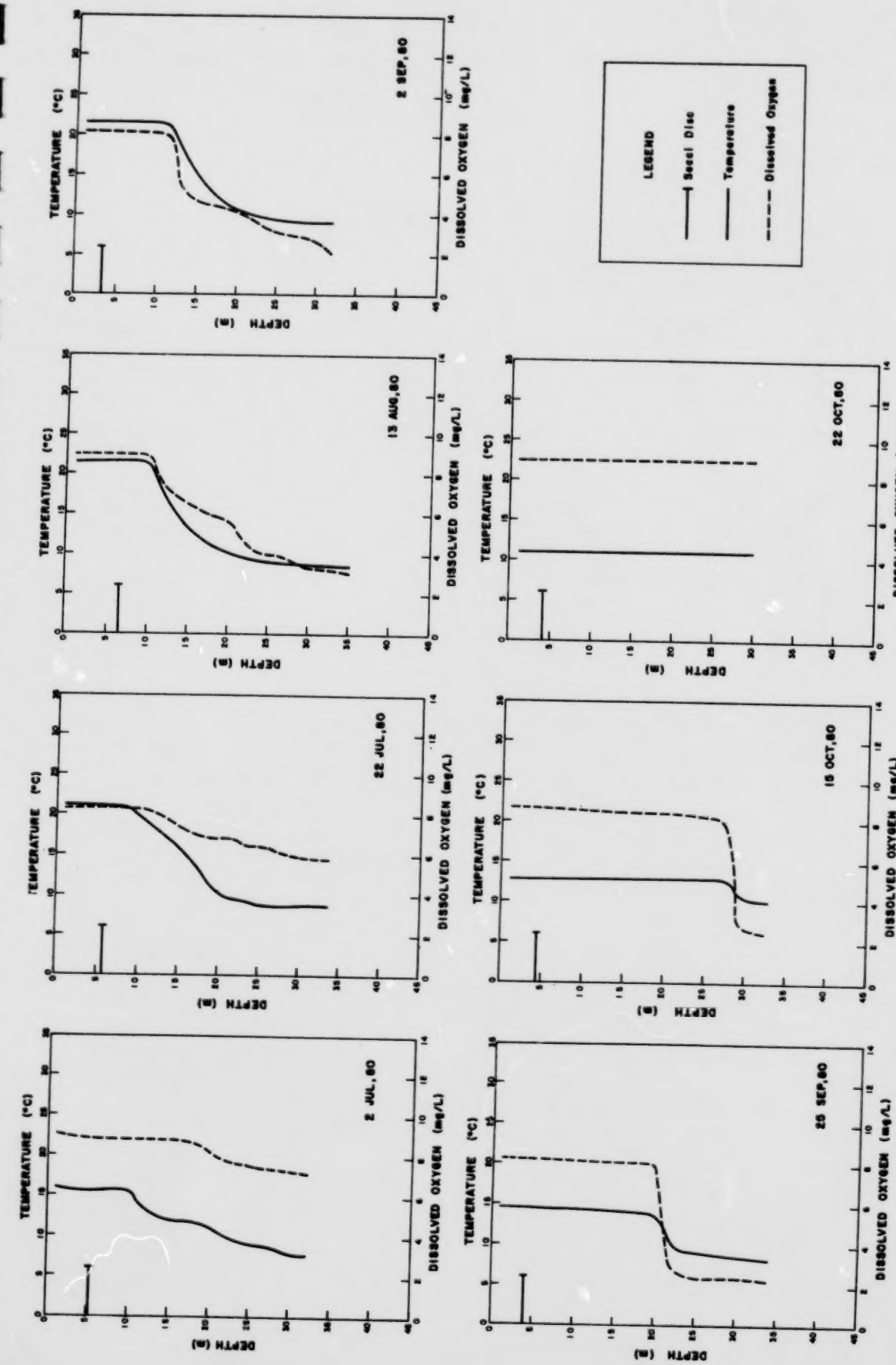


Figure 2 : Dissolved Oxygen and Temperature Profiles at Station K45 Lake Simcoe, Throughout the 1980 Sampling Period.

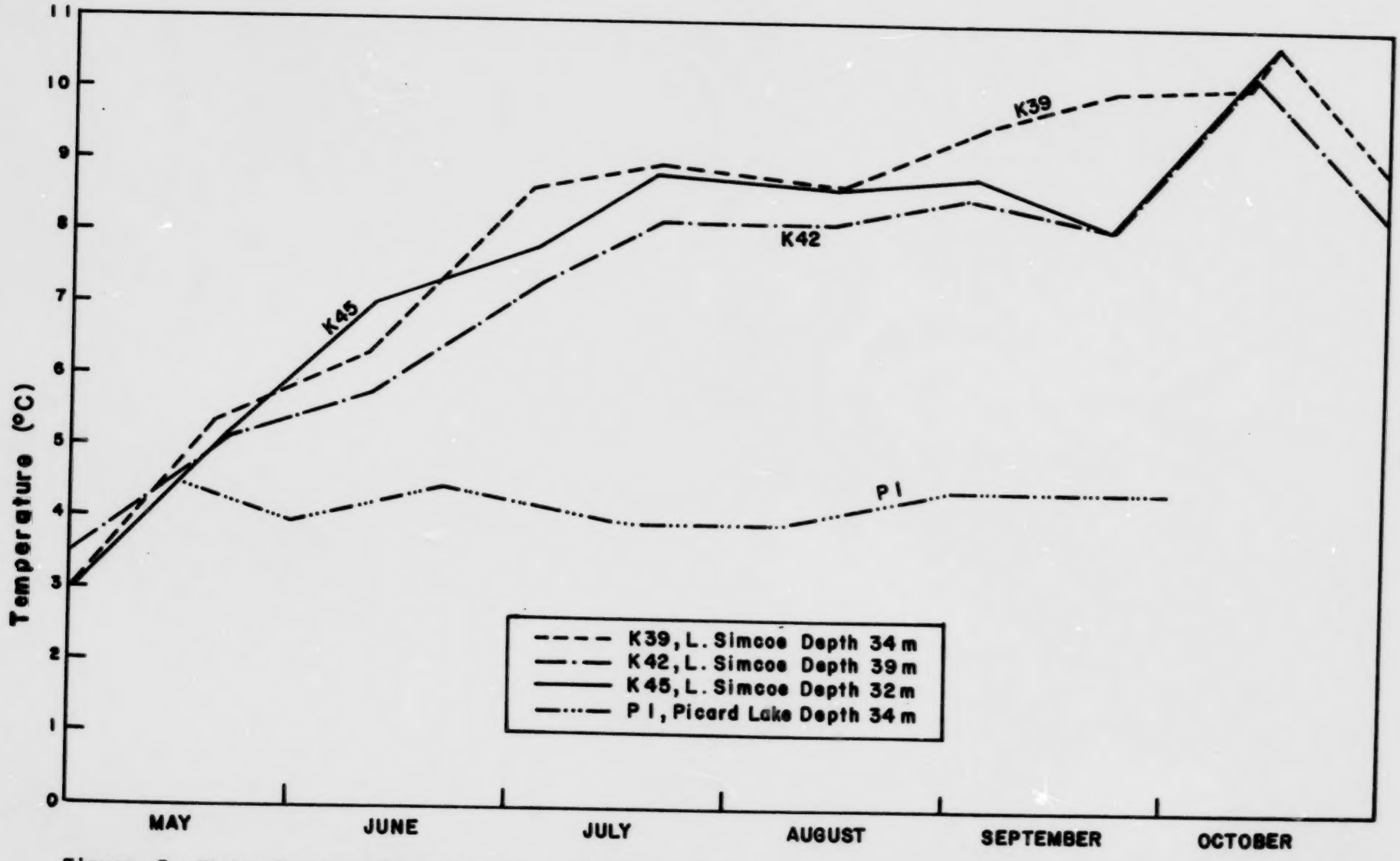


Figure 3 : Water Temperatures, 1.0 meters above bottom at Stations K39, K42, K45, Lake Simcoe (1980) and Station P1, Picard Lake (1978)

these three stations, and compares it to values measured in lakes of smaller surface area but comparable depths. As discussed earlier, these elevated bottom water temperatures are a function of the lake's broad surface area, versus its relatively shallow depth.

The second group of stations were located in relatively shallow water areas of the lake; E50 - 8 metres, E51 - 12 metres, N31 - 10 metres and C6 - 12 metres. No persistent thermal discontinuity developed at these stations.

The water depth was sufficiently shallow, that wind induced turbulence was sufficient to promote uniform heating throughout the water column. During calm periods, a temperature gradient of 4 to 6°C would develop through the depth of the water column, but this broke down under more turbulent conditions. The following table summarizes the maximum surface and bottom water temperature recorded at these stations and the maximum temperature variation through the water column.

Summary of Water Temperature Data for Stations E50, E51 and N31

Station	Max. Surface Temp. (°C)	Max. Bottom Temp. (°C)	Max. Temperature Variation Through Water Column (°C)
E50	22.7 (12/8/80)	22.8 (12/8/80)	4.0 (20/5/80)
E51	22.3 (12/8/80)	21.1 (3/9/80)	6.1 (12/8/80)
N31	22.1 (12/8/80)	21.7 (12/8/80)	4.9 (22/7/80)
C6	22.1 (13/8/80)	21.9 (13/8/80)	6.9 (21/7/80)

The depth of water (17.5 m) at the Group 3 station, C9, was sufficient to permit the development of a relatively stable temperature gradient; however, the water column did not stratify into distinct thermal layers. The maximum surface and bottom water

temperatures recorded at this station were 21.8 and 13.9°C respectively. A maximum temperature decrease of 9.2°C was measured through the depth of the water column on July 21, 1980.

1.4 Dissolved Oxygen

The presence of adequate dissolved oxygen is essential for sustaining a healthy, varied fish population and other aquatic life. The prime sources of oxygen in water bodies are the atmosphere and that produced through photosynthesis by plants.

At the time of spring turnover, the temperature of the water column is uniform and the dissolved oxygen concentration throughout it is at or near 100% saturation. As the temperature of the surface waters increases, due to the thermal inputs, the water column becomes stratified, and mixing of the upper and lower layers of water in a lake is not longer possible. When this occurs, the bottom waters are effectively cut off from further oxygen inputs.

Due to the oxygen consuming processes of chemical and bacterial decomposition, the oxygen content of the bottom waters is normally reduced during the period of thermal stratification. The severity of this oxygen depletion is in part governed by the enrichment status of the water body.

The gradual cooling of the upper layers of water through the fall, results in the entire water column reaching a homogenous temperature, at which time complete mixing throughout occurs and the entire water column is again at or near 100% oxygen saturation.

Similar to the discussion of the temperature data, the sampling stations have been divided into three groups to discuss dissolved oxygen: Group 1 - K45, K42 and 39; Group 2 - E50, E51, N31 to C6; and Group 3 - C9. C1 has not been included in the discussion due to the shallowness of the water column at this station, which remained near saturation throughout the study.

The dissolved oxygen profiles of the three Group 1 stations were all clinograde in character (dissolved oxygen concentrations decreased with depth), with the severity of the curve increasing over the sampling period. A series of dissolved oxygen profiles for Station K45, which are representative of the Group 1 stations, are illustrated in Figure 2. Prior to the formaton of a stable thermocline (late July - early August) the dissolved oxygen concentration in the lower portion of the lake remained in excess of 5.0 mg/L. Following stabilization of the thermacline there was a significant decline in hypolimnetic dissolved oxygen concentrations. The severity of this depletion was greater at Stations K39 and K42, than illustrated at K45 in Figure 2.

The following table summarizes the minimum dissolved oxygen concentrations measured at a depth of one metre above the bottom at these three stations, and the date on which the measurements were obtained.

Station No.	Minimum Dissolved Oxygen Concentration (mg/L) 1 metre above the bottom	Depths (m)	Date
K39	0.4	31	22/10/80
K42	0.0	39	22/10/80
K45	2.0	34	3/9/80

Using optimal conditions for lake trout of temperatures less than 10 °C and greater than 5 mg/L dissolved oxygen established by fisheries researchers (Scott and Crossman, 1975), it was possible to define the depth zone of optimal conditions for lake trout in the water column at station K45 (Figure 4). From mid-August through to fall turnover during the later portion of October, such preferred conditions were non-existent.

During this period, the trout would have been forced to occupy portions of the water column which provided less than optimal conditions. This situation also existed at Stations K42 and K45, for a comparable time period.

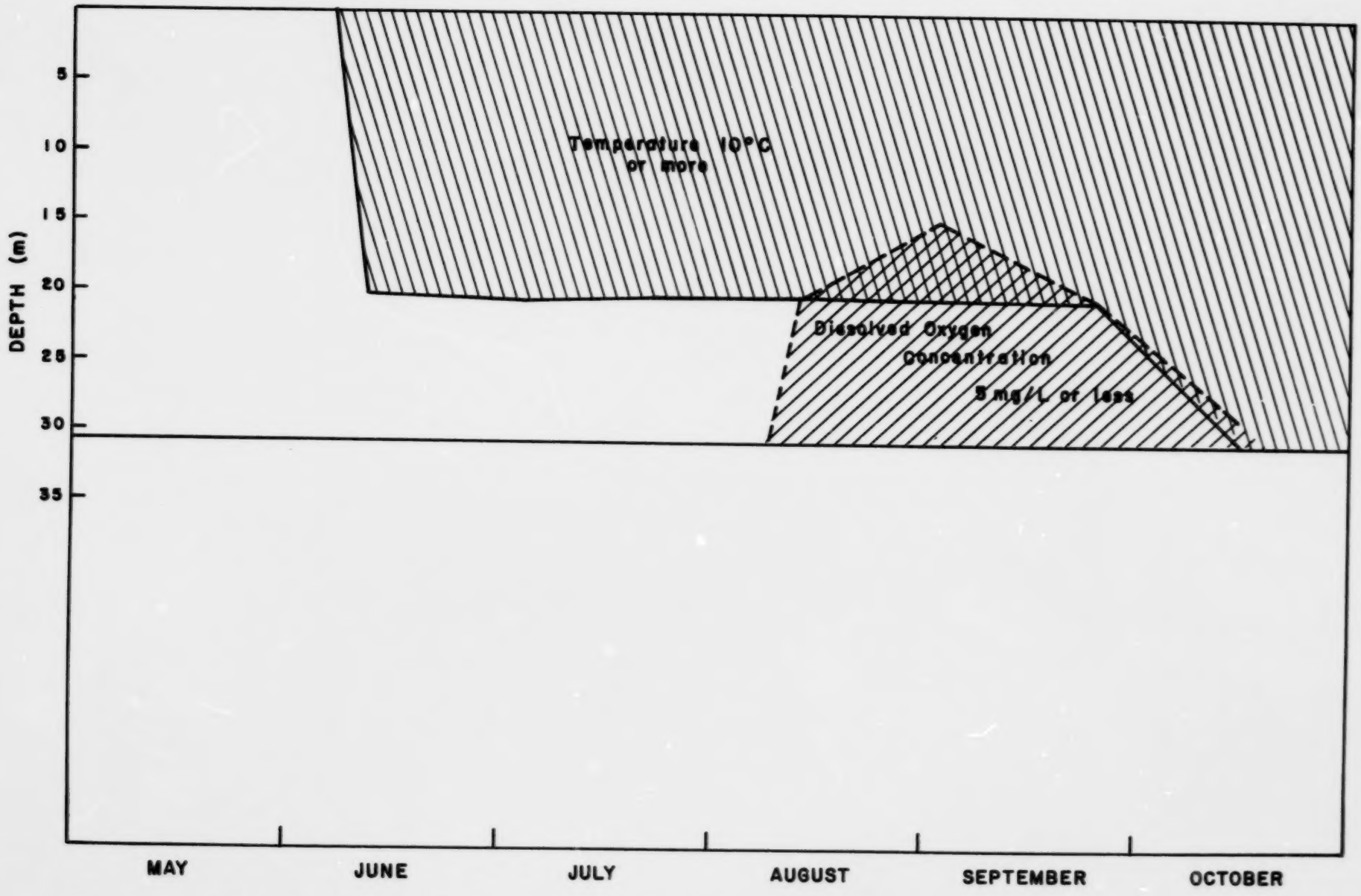


Figure 4 : Optimal Conditions for Lake Trout, Lake Simcoe K45 1980.

The dissolved oxygen profiles at the Group II stations (E50, E51, N31 and C6) were variable in character (Figure 5). As previously mentioned, the depth of water at these stations allowed for complete mixing. When the temperature profiles were isothermic; the dissolved oxygen concentration remained constant with increasing depth. During sampling periods when a temperature gradient existed through the water column, the dissolved oxygen profiles were clinograde in character. The severity of the dissolved oxygen depletion with depth was partially dependent upon the length of time a temperature disparity through the water column existed. The following table summarizes the minimum dissolved oxygen concentration measured one metre above the bottom at each of the Group II stations, and the date of the measurement.

Station No.	Minimum Dissolved Oyxgen Concentration (mg/L), 1 Metre Above the Bottom	Date
E50	7.1	22/7/80
E51	3.0	12/8/80
N31	5.3	22/7/80
C6	3.5	2/9/80

The dissolved oxygen profiles at the Group III station, C9, were clinograde in character. The severity of the dissolved oxygen depletion in the lower portion of the water column increased over the duration of the survey. A minimum concentration of 2.9 mg/L was recorded one metre above the bottom.

1.5 Water Chemistry Characteristics

Conductivity is a measure of the ability of a water to carry an electric current, which is dependent upon the concentration of various mineral salts. It can be used as a gauge to monitor changes in water quality and may indicate areas where water quality problems exists.

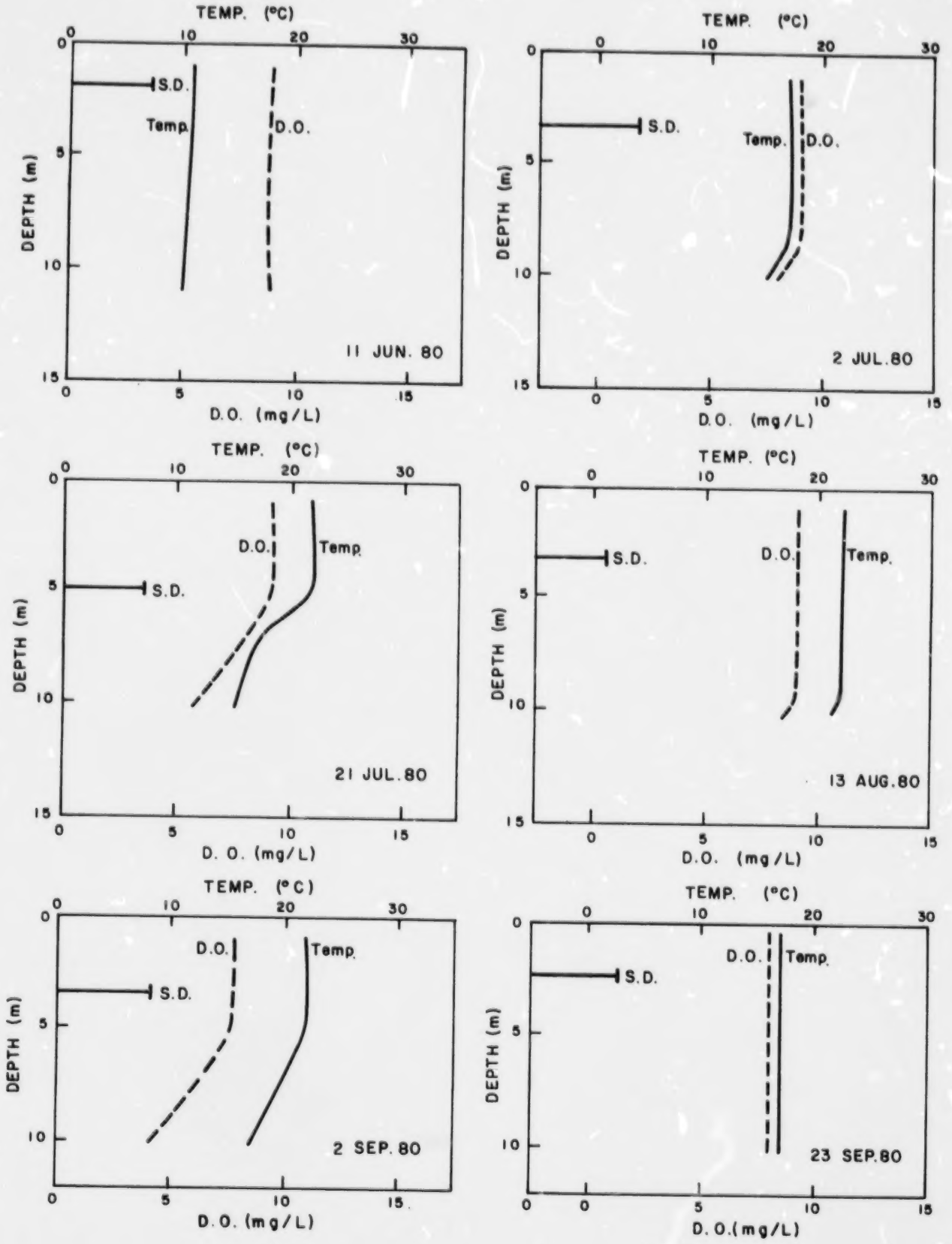


Figure 5 : Temperature and Dissolved Oxygen Profiles at Station C6 Lake Simcoe, over the 1980 Sampling Period.

Conductivity of Lake Simcoe averaged approximately 330 umhos/cm with very little horizontal variation and only a slight increase in the bottom waters. The conductivity of the Holland River was substantially high, averaging approximately 610 umhos/cm.

Iron, in sufficient concentrations, may impart a bitter taste to water and cause reddish-brown stains on plumbing fixtures and laundry. The Provincial water quality objective for iron in an unfiltered sample is 300 ug/L or less, to protect aquatic life.

The mean euphotic zone iron concentrations, at the nine lake stations, varied from 20 to 70 ug/L, all well below the Provincial objective. Generally, the euphotic zone values were representative of the entire water column, although a minimum build-up occurred in the bottom waters of Kempenfelt Bay. The mean iron concentration of the Holland River was substantially higher than that of the lake, averaging 510 ug/L.

Silica is extremely common in nature as a constituent of igneous rock, quartz and sand. It is significant in aquatic systems as the principal cell water component of a class of algae commonly called diatoms. The growth pattern of diatoms strongly influences the temperal and spacial distribution of silica. Silica is assimilated by diatoms in the synthesis of the cell wall and slowly returned to the water by resolution of the dead organisms.

The variations in mean euphotic zone silica concentrations among the nine lake stations were small; mean concentrations ranged from 0.60 to 0.77 mg/L. Silica concentrations in the Holland River were considerably higher, averaging 1.61 mg/L. The concentration of silica in the euphotic zone waters initially decreased from the levels measured in May to a minimum concentration in July and then subsequently decreased.

The silica concentrations in the bottom water were comparable to euphotic zone values, with the exception of the three deep water stations (K39, K42 and K45), where substantial build-up

occurred over the last half of the survey. The concentrations measured one metre above the bottom at K42 typify these accummulations, increasing from a minimum of 0.42 mgSi/L on July 3 to 2.10 mgSi/L on October 15, 1980. Similar concentration increases were evident in the lower 10 meters of the water column at all three of the deep water stations.

1.6 Nutrients

(a) Phosphorus

Phosphorus, which has been identified as the major nutrient stimulating algae and plant growth in lakes, was found in varying concentrations over the lake. The element phosphorus does not occur freely in nature but is found in the form of phosphates in several minerals and is a consitutent of fertile soils and plant and animal tissue. High levels of phosphorus may be found in industrial, domestic waste and land drainage waters.

The Holland River system, which receives inputs from the Aurora, Newmarket and Bradford sewage treatment facilities, plus the intensively farmed Holland Marsh area; and the Barrie and Orillia sewage treatment facilities are the major sources of phosphorus to Lake Simcoe, in excess of the natural inputs from the lake's drainage basin and precipitation.

Figures 6 and 7 illustrate the mean euphotic zone total and dissolved reactive phosphorus concentrations, plus provides the range of concentration for each station. The largest and most significant area of phosphorus enrichment was Cook Bay (C1, C6, C9). The second area was Kempenfelt Bay, as identified by stations K39 and K42. The remaining stations; K45, E50, E51 and N31 all displayed similar moderate phosphorus

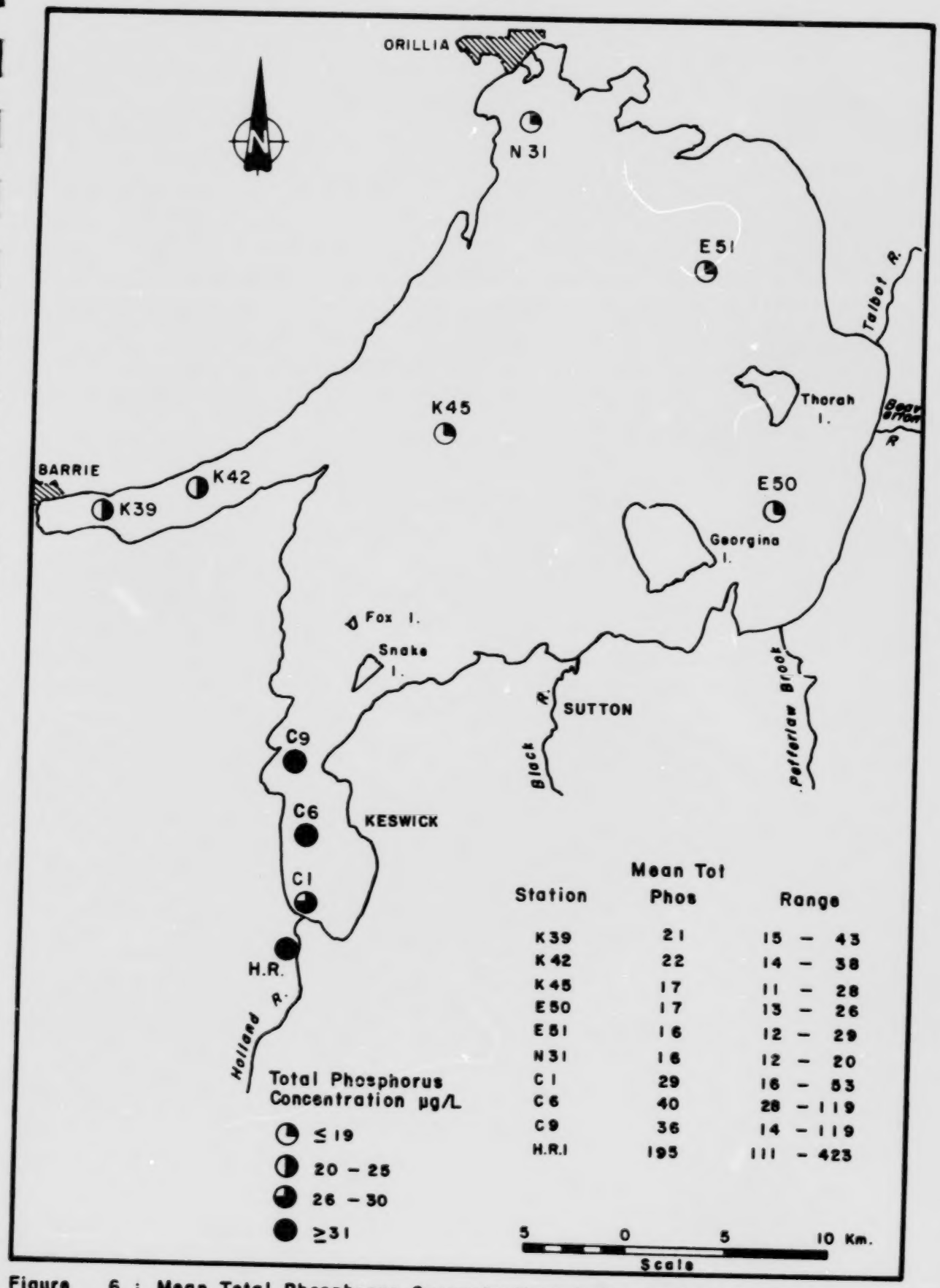


Figure 6 : Mean Total Phosphorus Concentrations in the Euphotic Zone of Lake Simcoe, 1980.

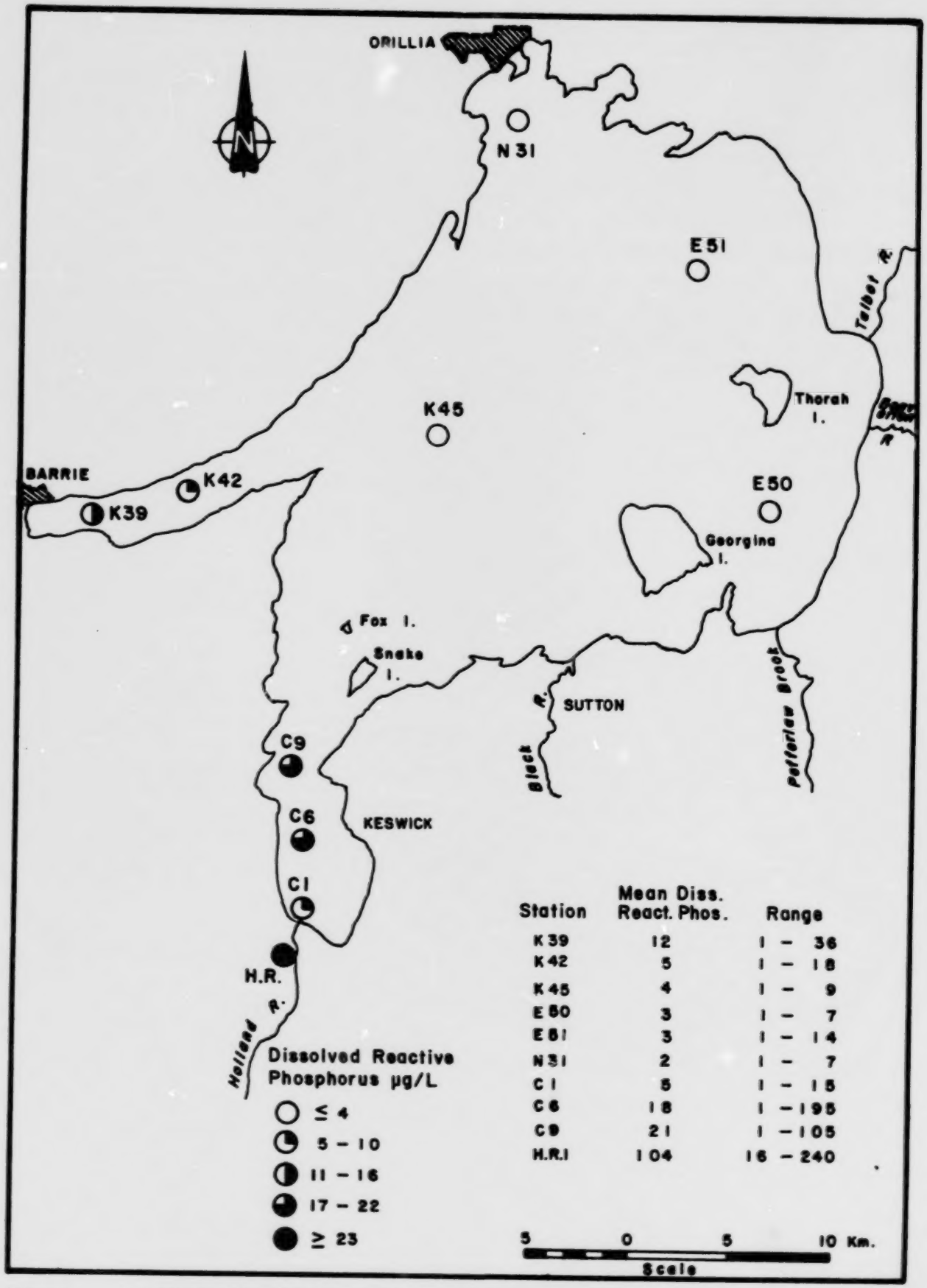


Figure 7 : Mean Dissolved Reactive Phosphorus Concentrations in the Euphotic Zone of Lake Simcoe, 1980.

concentrations. The stations will be discussed with respect to those areas having similar concentrations.

Figure 8 illustrates the concentration of total phosphorus in the euphotic zone waters of Cook Bay (C1, C6, C9), the waters of the Holland River. Mean total phosphorus concentrations in the Holland River exceeded the Cook Bay stations values by fourteen times and were twenty-four times those found in the lake proper as defined by the mean phosphorus concentration measured at K45. The phosphorus inputs of the Holland River have resulted in Cook Bay being the most enriched area of Lake Simcoe identified by this survey. This enrichment has manifested itself in extensive growths of aquatic weeds which routinely clog beaches in the area.

Table 2 presents the mean total phosphorus and mean dissolved reactive phosphorus concentrations, their ranges and percentage of dissolved reactive phosphorus to total phosphorus for both euphotic and bottom waters in Cook Bay and the Holland River.

Generally, total phosphorus concentrations in the Holland River increased from the May sampling period (111 ug/L), to a mid-summer peak of 423 ug/L and then declined again to 185 ug/L by September. Dissolved reactive phosphorus concentration was much more variable throughout the sampling period and did not display any similar trend. The percentage of dissolved reactive phosphorus to total phosphorus ranged from 14 to 57 per cent over the sampling period.

The July 21, 1980 sampling date was preceeded by two days of rain, during which 62 millimetres of precipitation fell. This heavy amount of precipitation resulted in extremely elevated phosphorus values at the Holland River station and to a lesser extent at the three Cook Bay stations. The total phosphorus concentration in the Holland River increased from 282 ug/L prior to the July 21, 1980 sampling to 423 ug/L on that date.

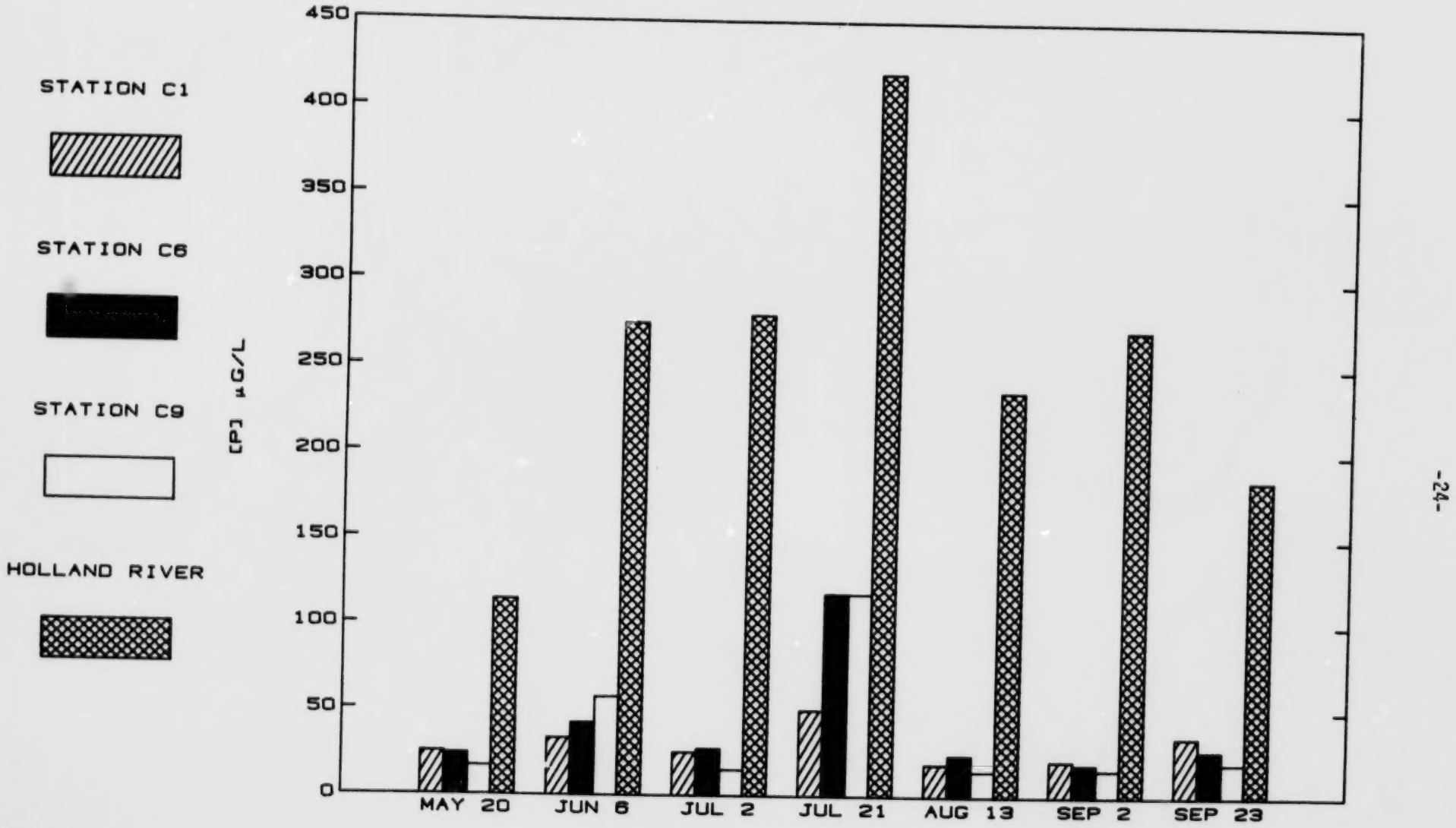


FIGURE 8 : EUPHOTIC ZONE TOTAL PHOSPHORUS CONCENTRATIONS AT STATIONS C1, C6, C9 IN COOK BAY AND TOTAL PHOSPHORUS CONCENTRATIONS IN THE HOLLAND RIVER, 1980.

TABLE 2

MEAN TOTAL PHOSPHORUS AND DISSOLVED REACTIVE PHOSPHORUS

Statistics for Euphotic and Bottom Waters in
Cook Bay and Holland River, 1980

Euphotic Waters

Stn. #	Mean Total Phosphorus ug/L	Range	Mean Dissolved Reactive Phosphorus ug/L	Range	% D.R.P.* of T.P.
Holland River	195	111-423	104	16-240	53
C1	29	16- 53	5	1-119	17
C6	40	19-119	18	1- 95	45
C9	36	14-119	21	1-105	58

Bottom Waters

Stn. #	Mean Total Phosphorus ug/L	Range	Mean Dissolved Reactive Phosphorus ug/L	Range	% D.R.P.* of T.P.
Holland River	--	--	--	--	--
C1	--	--	--	--	--
C6	24	19- 30	5	1- 8	21
C9	42	20-134	22	1- 78	52

* percentage of Dissolved Reactive Phosphorus of Total Phosphorus

Comparably, the dissolved reactive phosphorus concentration increased from 85 ug/L to 240 ug/L. Phosphorus levels subsequently decreased significantly, to concentrations lower than were measured prior to the rainfall. This significant increase was due to land runoff and other inputs resulting from this rainfall event.

Station C1 is located in Cook Bay, only a short distance from the mouth of the Holland River. The total phosphorus concentration at this station ranged from 16 to 53 ug/L and averaged 29 ug/L. Comparable to the Holland River, the maximum concentration was measured on July 21, 1980 following the heavy rainfall event, and is attributed to increased concentrations and flows in the Holland River. The dissolved reactive phosphorus concentration at this station ranged from less than 1 ug/L to 15 ug/L; the highest concentration again occurring on July 21, 1980.

Considerable variation in total and dissolved reactive phosphorus concentrations were recorded for the euphotic zone waters at C6 and C9 (Table 2). There was a significant increase in total phosphorous concentration at both stations on June 11, 1980. Total phosphorus concentrations on this date had increased by 75 per cent at C6 and 195 per cent at C9 from the preceeding sampling date. Concentrations had declined by the subsequent sampling date (June 2, 1980), but were elevated dramatically on July 21, 1980. By the subsequent sampling date (August 13, 1980), phosphorus concentrations had returned to approximately the same level as measured on July 2, 1980. Specific concentrations for these sampling dates are presented in the following table:

Date	Stn. C6 T.P.	Stn. C6 D.R.P.	Stn. C9 T.P.	Stn. C9 D.R.P.
2/7/80	26	11	14	1
21/7/80	119	95	119	105
13/8/80	24	1	16	2

T.P. - total phosphorus concentration - ug/L
D.R.P. - dissolved reactive phosphorus concentration - ug/L

The above data is representative of the entire water column for these two stations on these sampling dates.

The increased concentrations on July 21, 1980 at C6 and C9 are thought to be related to the heavy rainfall immediately preceeding the sampling date. However, based on the data collected, they do not appear to be directly related to an increased discharge of phosphorus-enriched waters from the Holland River. If this had been the case, phosphorus concentrations at C1, the station nearest the mouth of the river, should have been of a similar magnitude, yet they were 50 per cent lower. Similarly, an increase in conductivity at the Cook Bay stations would have been expected given that the conductivity of the Holland River was approximately 600 umhos/cm, almost double that of Cook Bay (330 umhos/cm), yet no significant change was recorded.

Figure 9 illustrates the total and dissolved reactive euphotic zone phosphorus concentrations for stations K39 and K42. The initial concentrations measured in May were elevated, especially at K39. This phenomena has been noted during previous year's surveys and is probably attributable to a build-up of phosphorus under ice from the effluent discharge of the Barrie sewage treatment facility. Total phosphorus concentrations had decreased by the subsequent sampling date and then remained relatively constant until mid-October, when concentrations increased as fall turnover approached. The significant exception to this was an elevated total phosphorus concentration at station K45 on July 4, 1980. This increase did not correlate with any of the other parameters measured, and may be an anomalous piece of data.

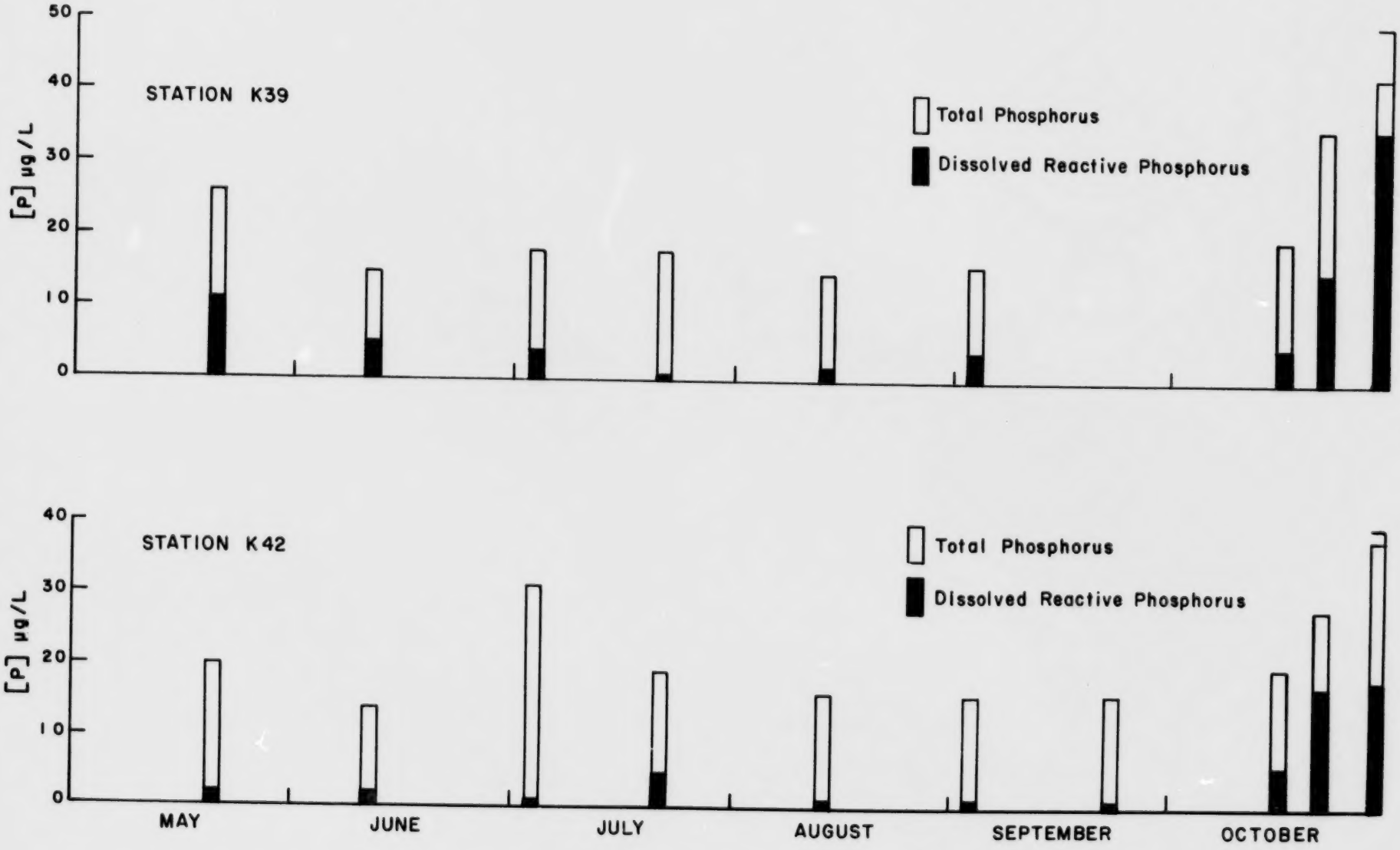


Figure 9 : Euphotic Zone Phosphorus Concentrations at Stations K39 and K42, 1980.

The dissolved phosphorus concentrations follow the same general trend as the total phosphorus concentrations though concentrations at K39 were generally higher than at K42.

Figures 10 and 11 illustrate the total and dissolved reactive phosphorus concentrations one metre above the bottom at K39 and K42, plus the dissolved oxygen concentration at this depth. Similar to the euphotic zone waters, the intial concentrations measured in May at K39 were elevated in comparison to those on the subsequent sampling date. There was a build-up of phosphorus at this depth over the duration of the survey and the percentage of dissolved reactive phosphorus to total phosphorus increased. The rate of build-up increased towards the latter portion of the survey, with concentrations peaking at or just prior to fall turnover. The maximum concentrations measured one metre above the bottom at these two stations are given below:

Station	T.P. (ug/L)	D.R.P. (ug/L)
K39	80	63
K42	115	78

This build-up was evident through the lower 5 to 6 metres of the water column, though concentrations decreased with increasing distance from the bottom. Concurrent with the increase in phosphorus concentrations were increases in ammonia, nitrate and silica levels.

Station K45 typifies the portion of the main lake having a water depth of 30 metres or greater. The euphotic zone total and dissolved reactive phosphorus concentrations for this station are presented in Figure 12. From May 20 to July 31, 1980, there was a steady increase in the total phosphorus concentration (13-24 ug/L), subsequented by a decrease over the remainder of the sampling period, with evidence of a slight increase prior to fall turnover.

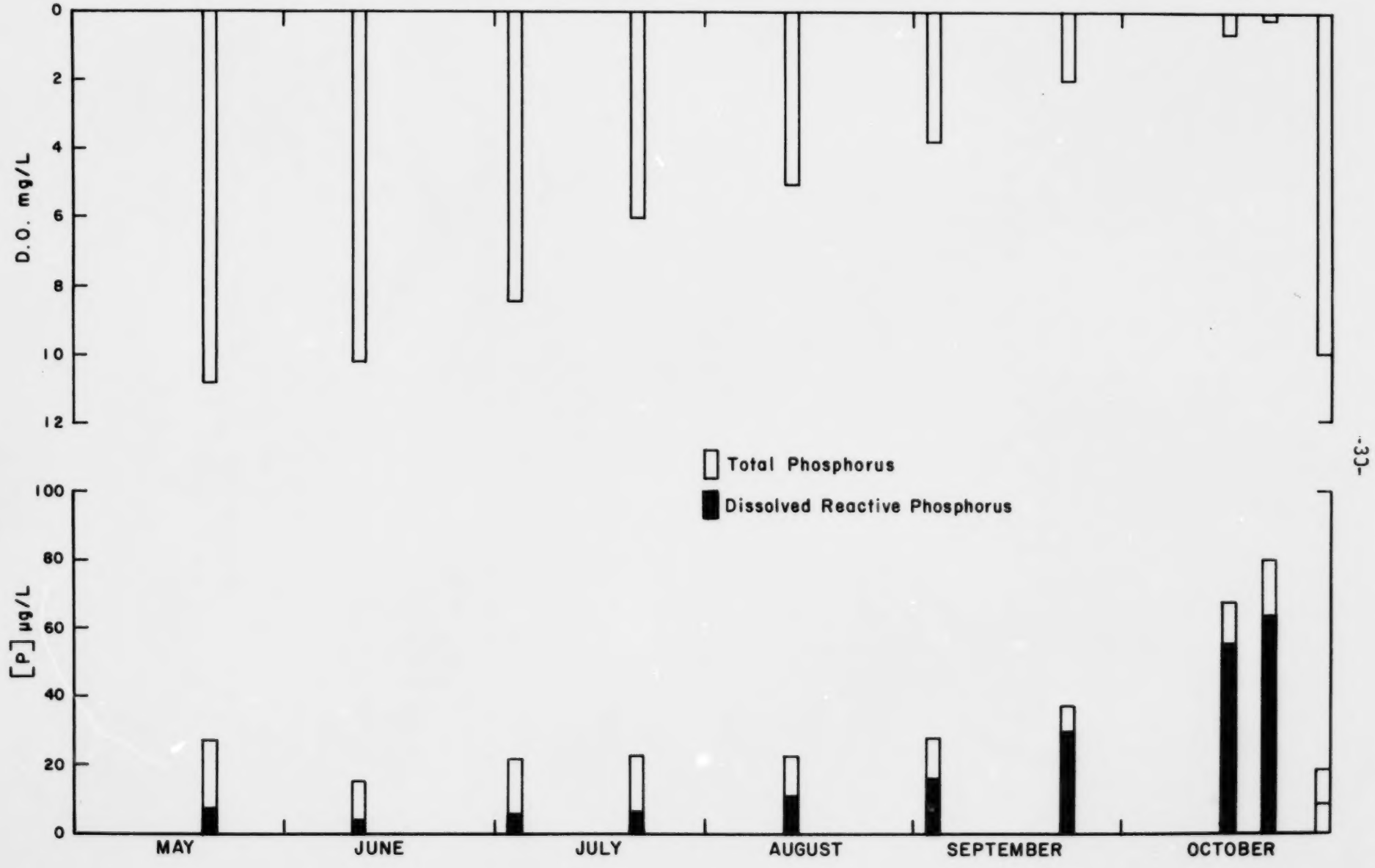


Figure 10 : Phosphorus and Dissolved Oxygen Concentrations at 1 m off the Bottom, K39, 1980.

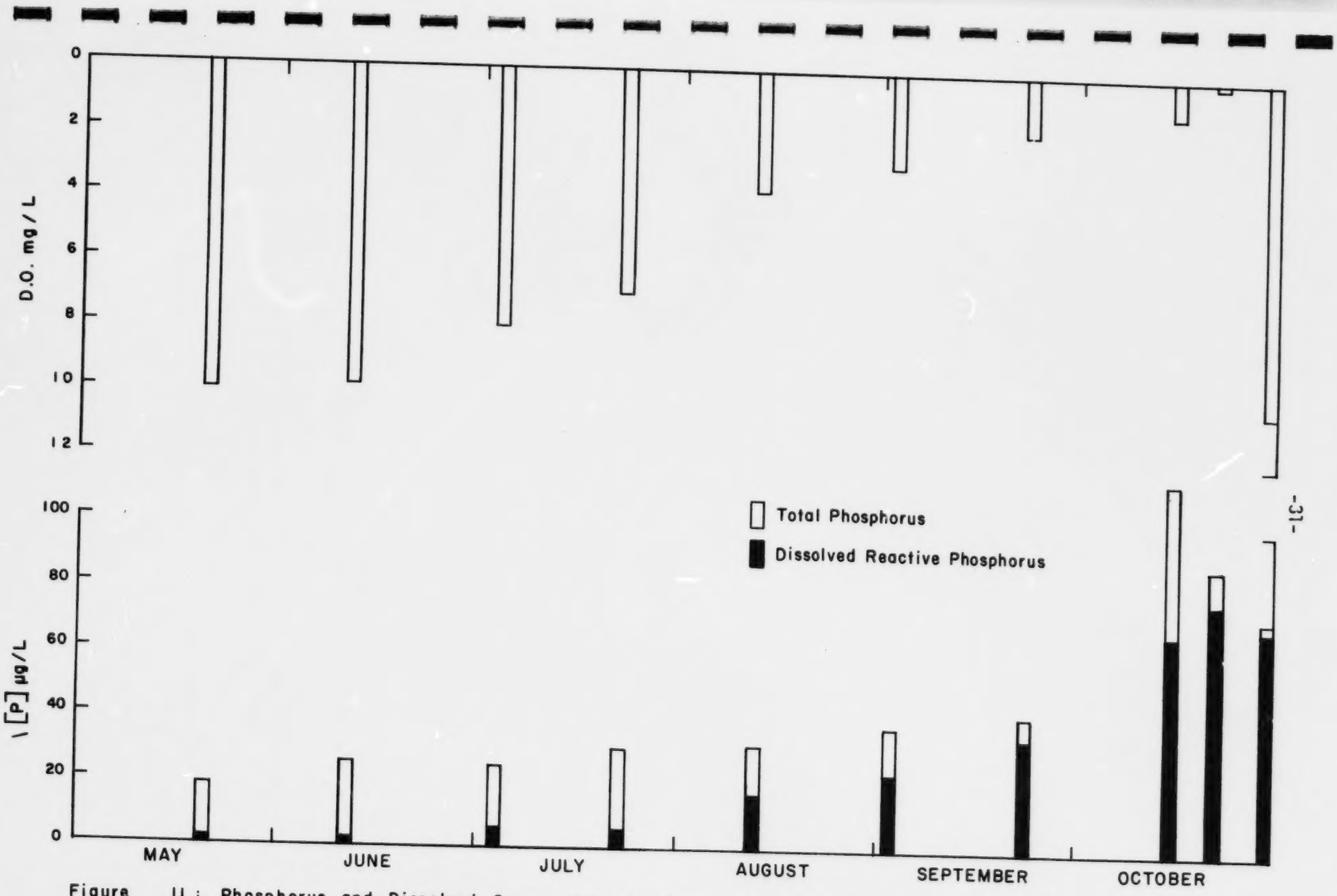


Figure 11 : Phosphorus and Dissolved Oxygen Concentrations at 1 m off the Bottom K42, 1980.

The dissolved reactive phosphorus concentrations parallelled this trend.

Maximum concentration measured on July 21, 1980 coincided with the maximas measured at the three Cook Bay stations, and as mentioned previously, this date was preceeded by two days of precipitation. However, no increases in phosphorus concentration were noted on this date at the other five lake sampling locations.

Figure 13 illustrates the total and dissolved reactive phosphorus and dissolved oxygen concentrations one metre above the bottom at station K45. Phosphorus concentrations increased significantly from a first sampling date to July 2, 1980. This peak in concentration was not evident in any other portion of the water column sampled, although a similar increase was noted one metre above the bottom at K42 on this date.

Subsequent to this peak, phosphorus concentrations declined until mid-August then increased significantly as fall turnover approached. The maximum total and dissolved reactive phosphorus concentration recorded one metre above the bottom were 90 and 69 ugP/L respectively. Comparable to K39 and K42, this build-up of phosphorus was evident through the lower 5 - 6 metres of the water column, though concentrations decreased with increasing distance from the bottom. Concurrent with the increase in phosphorus concentrations were increases in ammonia, nitrite, and silica levels.

The other three open lake stations (N31, E50 and E51) were located in considerably shallow water than K45, and the euphotic zone frequently extended through the entire depth of the water column. The mean euphotic zone phosphorus concentrations at these stations were comparable to K45 as illustrated in Figure 6. When discrete samples were obtained from one metre above the bottom (i.e. when the euphotic zone did not encompass the entire water column), the phosphorus concentrations were comparable to those of the euphotic zone. Generally, the variation in concentration between

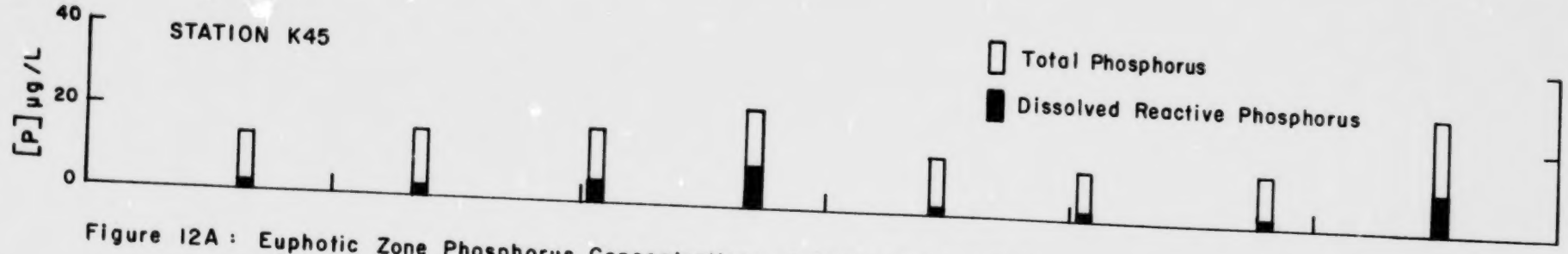


Figure 12A : Euphotic Zone Phosphorus Concentrations at Station K45, 1980.

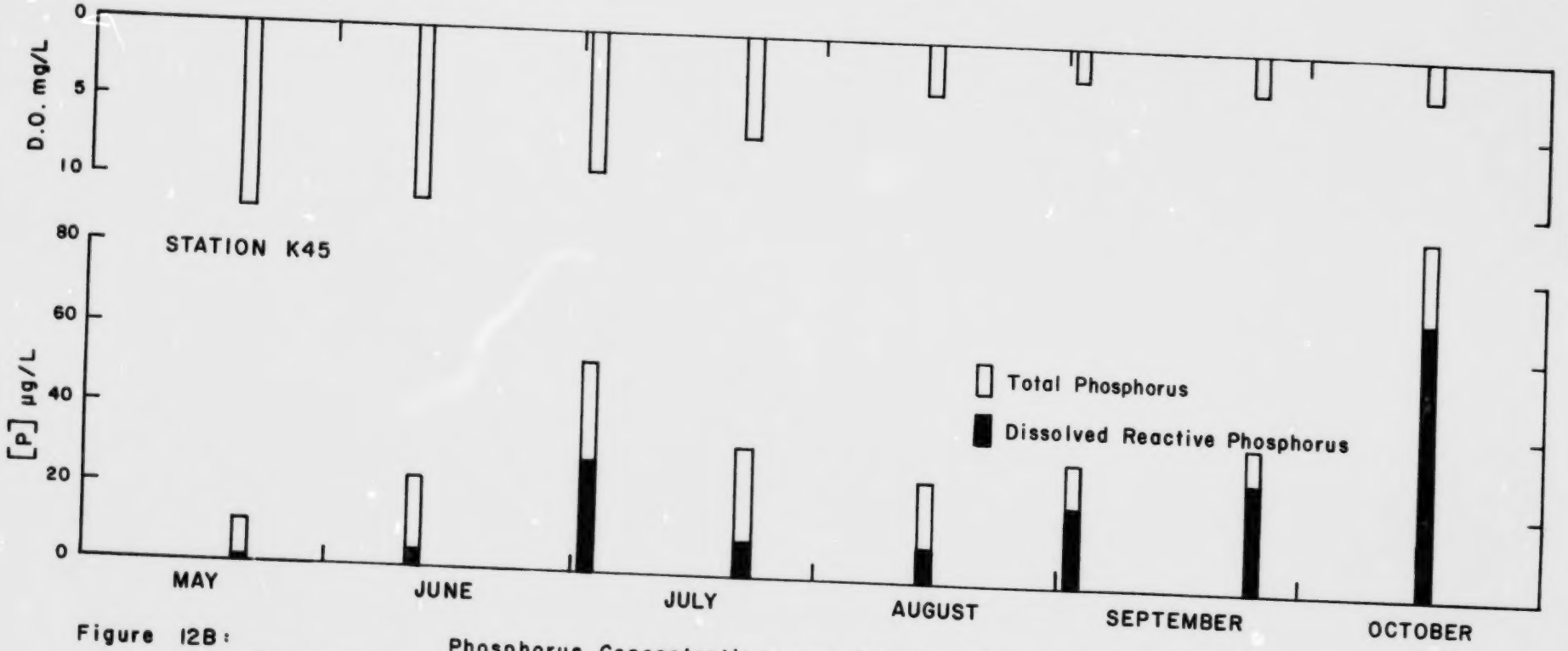


Figure 12B: Phosphorus Concentrations and Dissolved Oxygen Concentrations at 1 m off the Bottom Station K45, 1980.

sampling dates was minor, although the phosphorus concentrations had increased significantly at all three stations on the last sampling date in mid-October.

(b) Nitrogen

Nitrogen is an essential element required by all living organisms. The principle forms of nitrogen occurring in aquatic ecosystems are ammonia, nitrate, and nitrite (inorganic forms) and organic nitrogen. Through bacterial action, complex organic nitrogen compounds (e.g. protein) undergo changes to inorganic forms (ammonia, nitrites and nitrates). Inorganic forms (i.e. nitrate) can be reconverted to organic compounds through assimilation by algae and aquatic macrophytes.

Principle sources of nitrogen to the aquatic ecosystem are urban and agricultural land drainage, treated sewage effluent discharges, precipitation and direct fixation of atmospheric nitrogen by some forms of algae.

The mean euphotic zone total Kjeldahl nitrogen concentrations are illustrated in Figure 13; the table at the bottom of this figure summarizes the data. Except for the Holland River and the lower half of Cook Bay, concentrations were fairly uniform over the lake. The highest concentrations were measured in the Holland River (1.61 mg/L) and the influence of the river was evident in the higher concentrations in the lower half of Cook Bay.

The mean euphotic zone concentration for the nine lake stations was 0.40 mg/L. Variations in the concentration of total Kjeldahl nitrogen with depth were minimal and the euphotic zone values are representative of the entire water column.

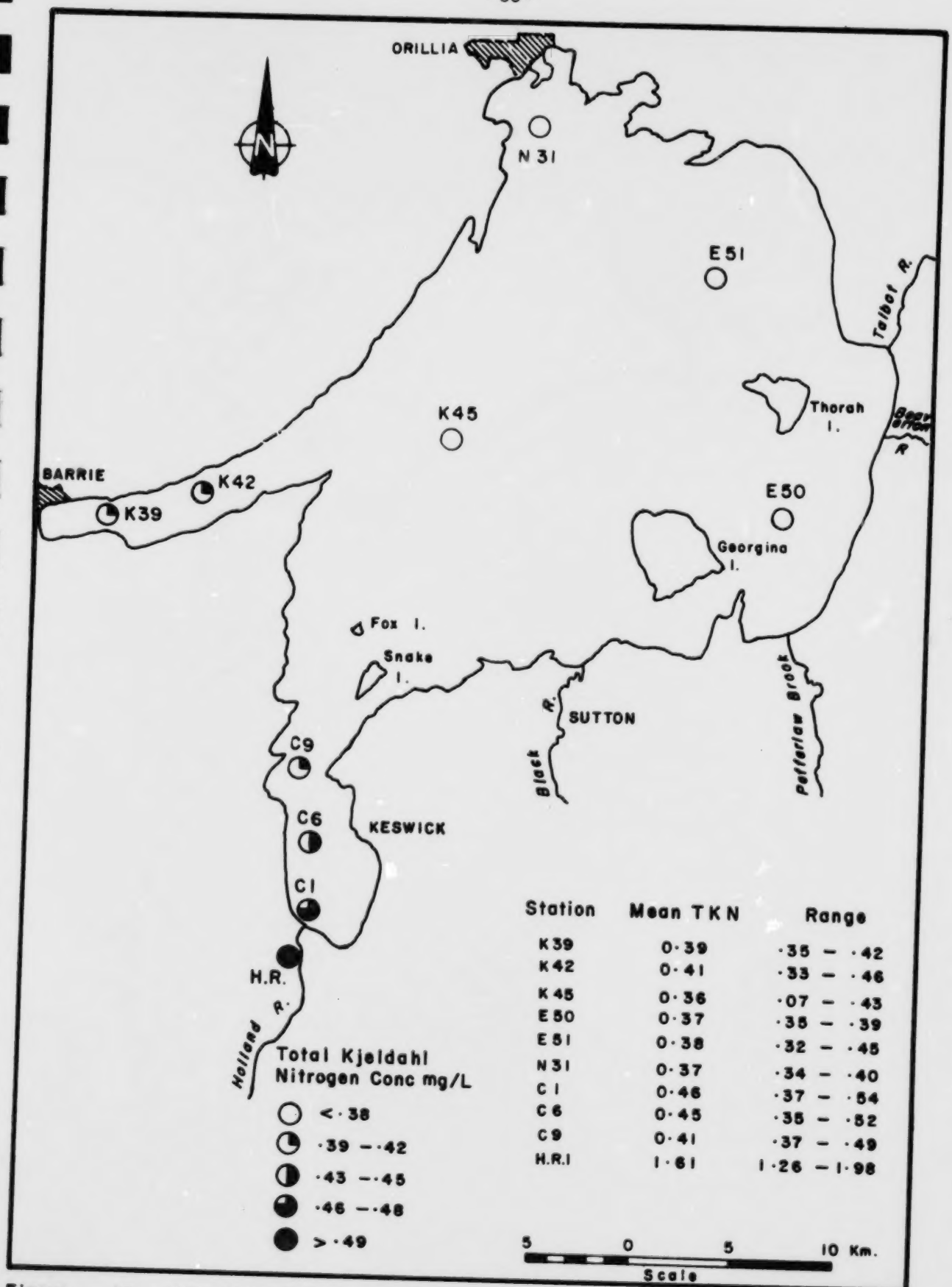


Figure 13 : Mean Total Kjeldahl Nitrogen Concentrations in the Euphotic Zone of Lake Simcoe, 1980.

The mean euphotic zone ammonia nitrogen concentrations are illustrated in Figure 14; the table at the bottom of this figure summarizes the data. Concentrations were lowest in the northern and eastern portion of the lake, while Kempenfelt Bay, the central portion of the lake and the lower end of Cook Bay had slightly higher concentrations. Higher concentrations were found in the upper portion of Cook Bay (C6 & C9) while the highest concentrations were measured in the Holland River. The concentrations in the Holland River were also the most variable, ranging from 0.006 to 0.262 mg/L.

Towards the end of the summer stagnation period, there was a substantial increase in ammonia concentrations in the bottom waters at the three deep water sampling locations (K39, 42 & 45). This increase was restricted to the lower 10 metres of the water column with concentrations decreasing with increasing distance from the bottom. The concentrations, one metre above the bottom at K42, illustrated in Figure 15 were representative of those found at the three deep water stations.

Figure 16 illustrates the main euphotic zone nitrate nitrogen concentration; the table at the bottom of this figure summarizes the data. Nitrate concentrations were uniform across most of the lake, except for Kempenfelt Bay, where the highest concentrations were measured near the head of the bay (K39), with concentrations decreasing proceeding easterly to the main body of the lake.

Nitrate nitrogen concentrations in the Holland River varied substantially. The highest concentration (0.507 mg/L), measured on May 5, 1980, reflected the high nitrate content of the pump-off water from the Holland Marsh, which is discharged to the Holland River. Three weeks later, the nitrate level was reduced to 0.007 mg/L. In response to a major rainfall event, and pumpage water from the Holland Marsh, the concentration on July 21, 1980 had increased to 0.141 mg/L. During the remainder of the sampling period, the nitrate concentration of the Holland River station was less than 0.005 mg/L.

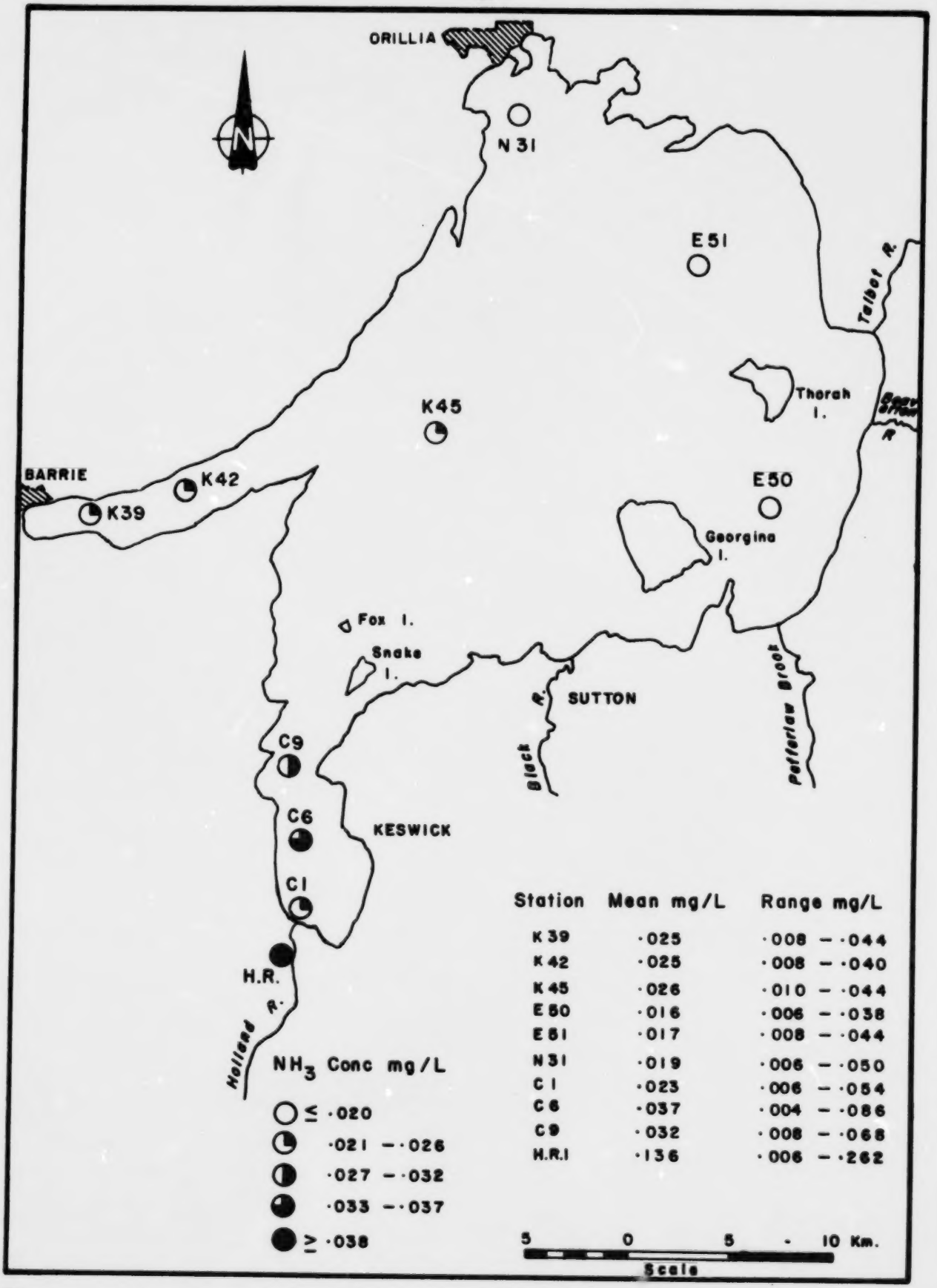


Figure 14 : Mean Ammonia Concentrations in the Euphotic Zone of Lake Simcoe, 1980.

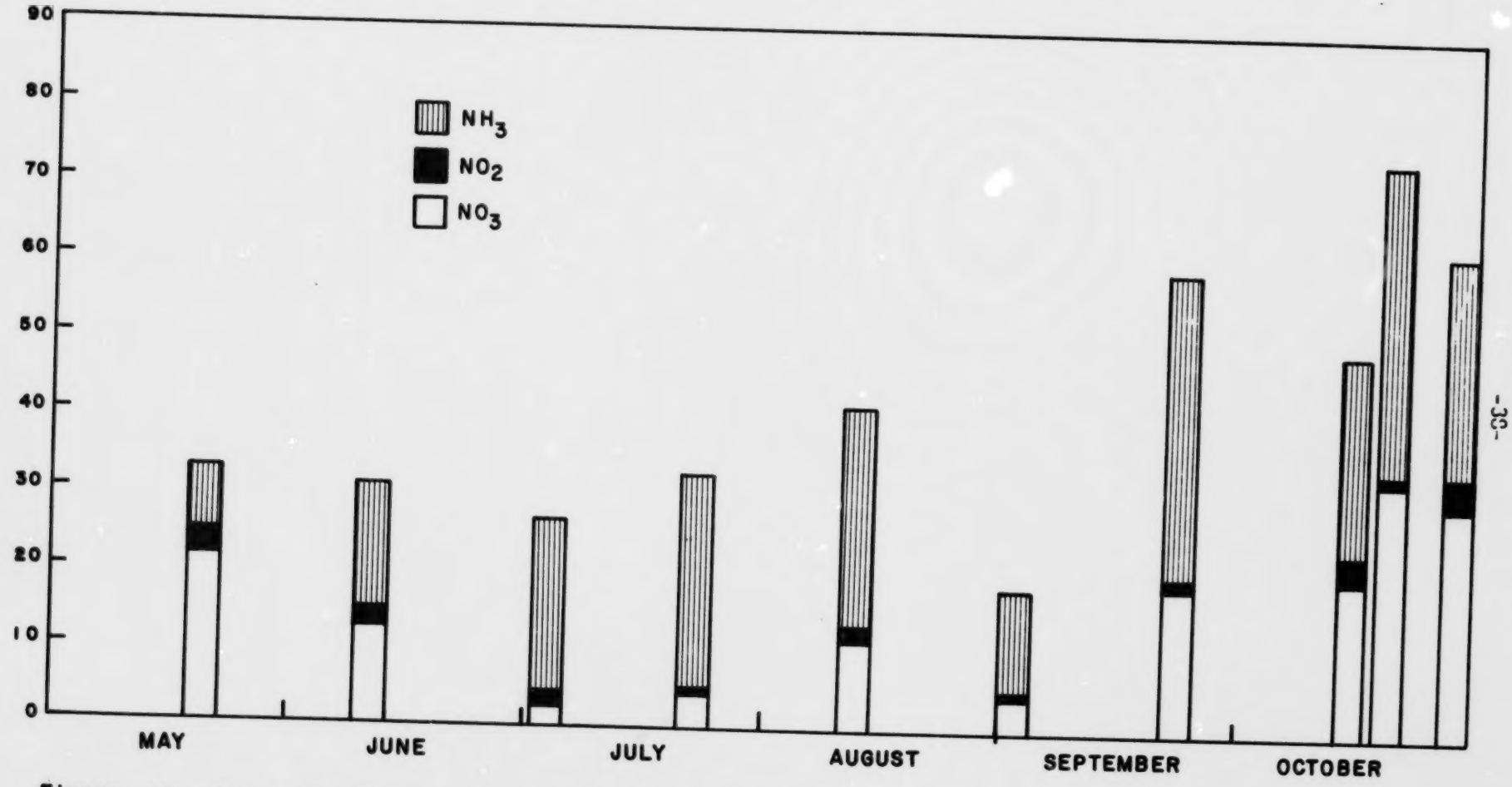


Figure 15 : Inorganic Nitrogen Concentrations Measured 1 m above the Bottom at Station K42, 1980.

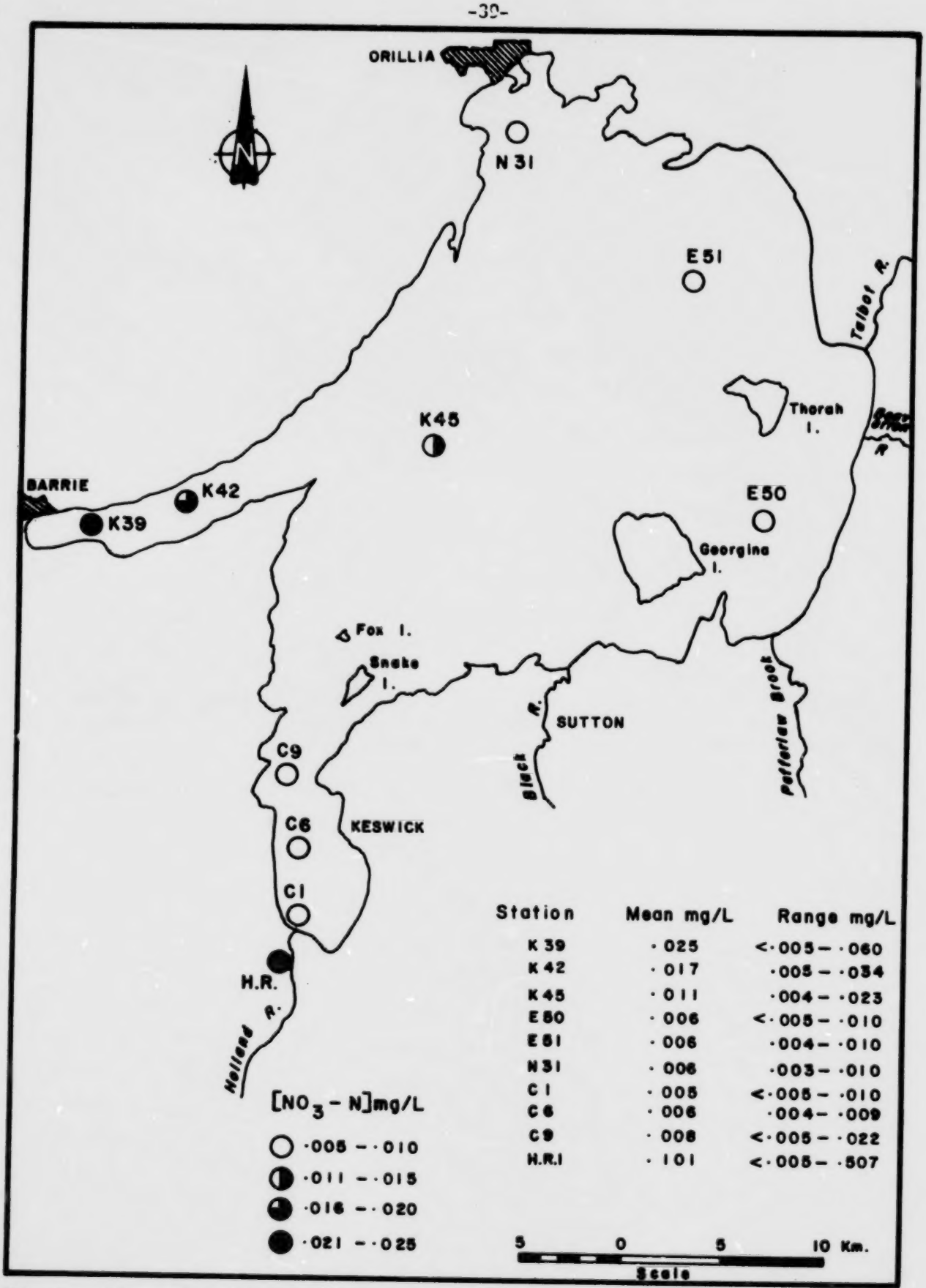


Figure 16 : Mean Nitrate Nitrogen Concentrations in the Euphotic Zone of Lake Simcoe, 1980

At the three deep water stations (K39, 42 & 45) there was a build-up of nitrate nitrogen in the bottom waters commencing in the early part of August, as illustrated by Figure 16. This build-up was primarily restricted to the lower 10 metres of the water column with concentrations decreasing with increasing depth from the bottom.

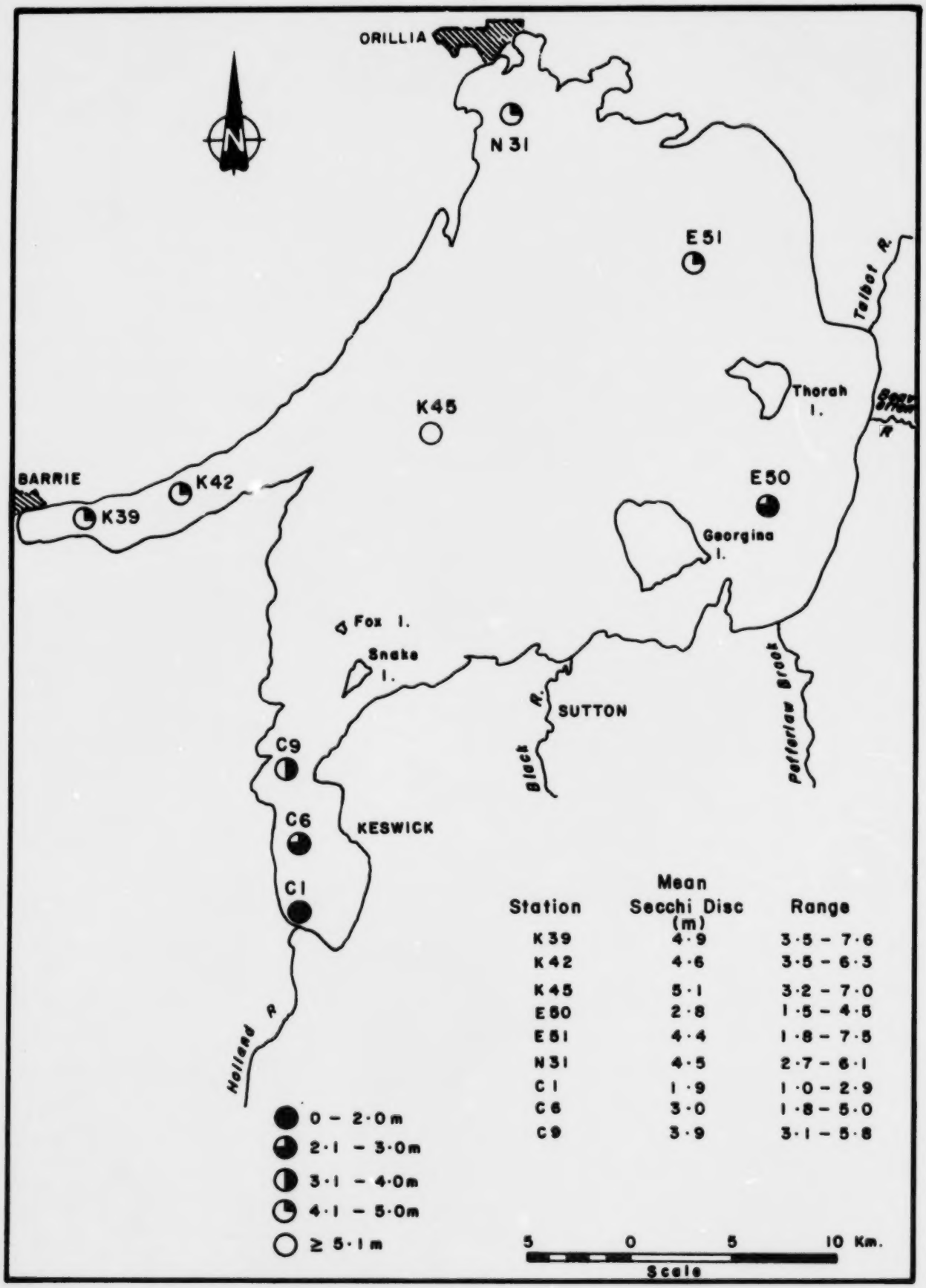
Euphotic zone nitrite concentrations were uniformly low across the lake, ranging from less than 0.001 to 0.007 mg/L. Bottom water concentrations were comparable to those found in the euphotic zone, except at the three deep water stations (K39, 42 & 45). Nitrate concentrations one metre above the bottom at these three stations ranged from less than 0.001 to 0.027 mg/L, with the highest concentrations occurring at K39.

The Holland River nitrite concentrations were higher than those found in the lake, ranging from 0.003 to 0.033 mg/L and averaging 0.018 mg/L.

1.7 Water Clarity and Chlorophyll a

The degree of water clarity in non-coloured lakes, such as Lake Simcoe, is determined in part by the density of suspended algae. Generally, the lower the density of suspended algae, the greater the degree of water clarity and vice versa. Because water clarity is also affected by other suspended particulate matter, surface conditions, the amount of cloud cover and time of day, only mean values for each station are used for the comparision purposes.

Figure 17 illustrates the mean Secchi disc measurements and provides the range of measurements for each of the lake stations. The degree of water transparency vary considerably. The mean readings range from 1.9 to 5.1 metres. The overall average Secchi disc reading for the lake was 3.9. metres.



Station	Mean Secchi Disc (m)	Range
K39	4·9	3·5 - 7·6
K42	4·6	3·5 - 6·3
K45	5·1	3·2 - 7·0
E50	2·8	1·5 - 4·5
E51	4·4	1·8 - 7·5
N31	4·5	2·7 - 6·1
C1	1·9	1·0 - 2·9
C6	3·0	1·8 - 5·0
C9	3·9	3·1 - 5·8

Figure 17 : Mean Secchi Disc Measurements at Nine Sampling Stations, Lake Simcoe, 1980.

The degree of water clarity was lowest at Station C1 but improved progressing north up the bay towards the open lake. The highest degree of water clarity was measured at Station K45.

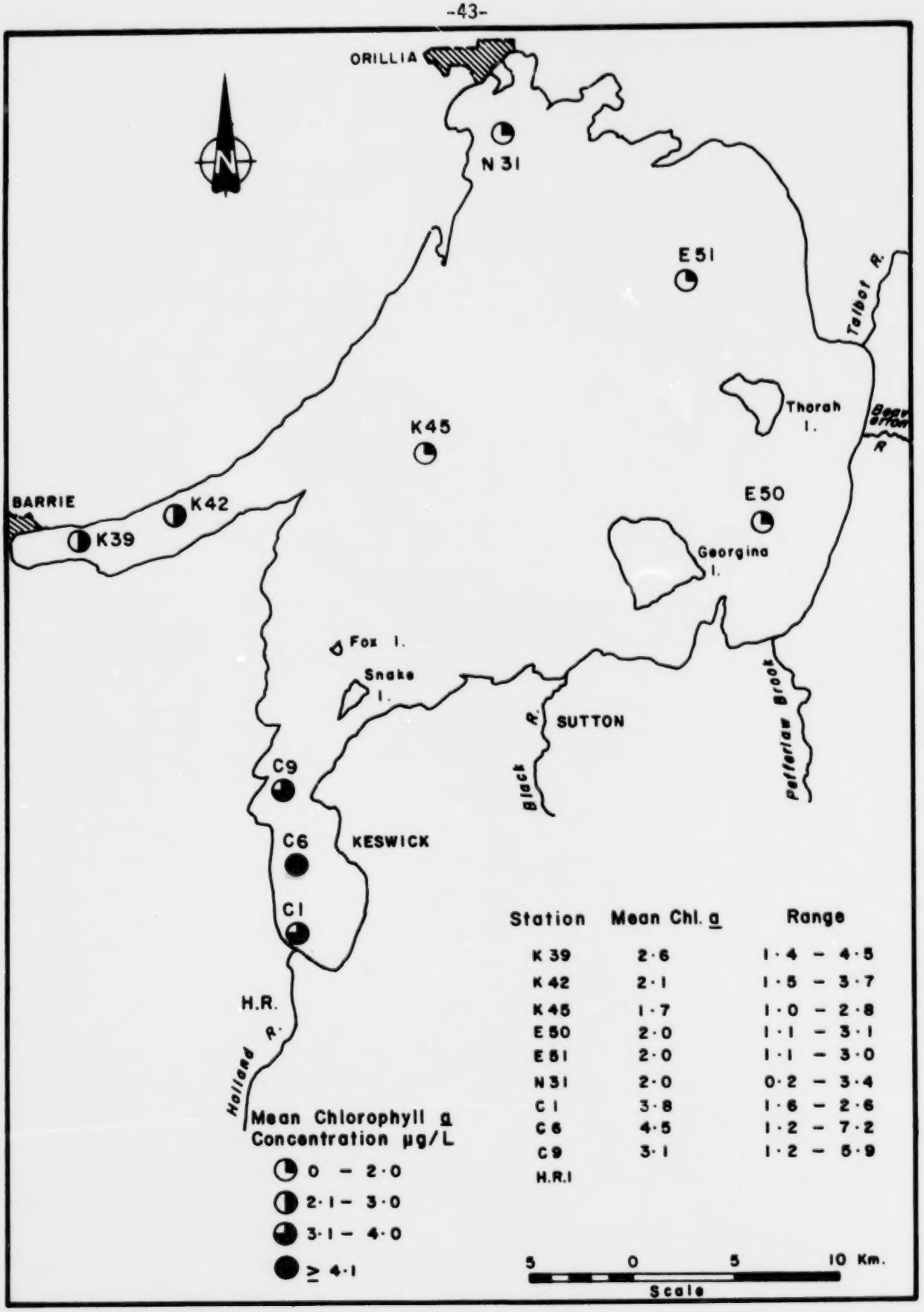
The poor water quality at Station C1 was partly due to a higher density of suspended and dissolved particulate matter (turbidity) at this location caused both by the shallowness of the water and proximity to the mouth of the Holland River. This reduction in quality would also decrease potential algal production in this area. Generally the maximum Secchi disc readings were recorded during the mid-summer period. It should be noted that at this time numerous Secchi disc readings were on the bottom at the shallower stations.

Chlorophyll a is a green photosynthetic pigment which is common to all classes of algae. The concentration of chlorophyll a thus provides an indication of the density of suspended algae.

The mean chlorophyll a concentrations are illustrated in Figure 18 and the concentration ranges for each station are given in the table at the bottom of this figure. Comparable to the Secchi disc readings, the mean chlorophyll a concentrations vary considerably, ranging from a low of 1.7 ug/L at Station K45 to a high of 4.5 ug/L at Statio C6. The overall mean concentration for the lake was 2.6 ug/L.

The mean chlorophyll a concentrations throughout the main body of the lake were 2.0 ug/L or less. Concentrations were slightly higher in Kempenfelt Bay while the highest concentrations were found in Cook Bay.

Except at Station C1, the lowest chlorophyll a concentrations occurred in July, corresponds to the highest measurements in water transparency.



Station	Mean Chl. a	Range
K 39	2·6	1·4 – 4·5
K 42	2·1	1·5 – 3·7
K 45	1·7	1·0 – 2·8
E 50	2·0	1·1 – 3·1
E 51	2·0	1·1 – 3·0
N 31	2·0	0·2 – 3·4
C 1	3·8	1·6 – 2·6
C 6	4·5	1·2 – 7·2
C 9	3·1	1·2 – 5·9
H.R.I		

Figure 18 : Mean Summer Chlorophyll a Concentrations at Nine Sampling Stations, Lake Simcoe, 1980.

TABLE 3

Mean Secchi Disc Rading and Chlorophyll a Concentration
for Stations K39, K42 and K45, 1975-1980

	K39		K42		K45	
	S.D. (m)	Chl. a (ug/L)	S.D. (m)	Chl. a (ug/L)	S.D. (m)	Chl. a (ug/L)
1975	4.9(9)	3.2(9)	4.8(8)	2.8(9)	5.0(7)	2.3(7)
1976	5.0(8)	3.1(6)	5.6(7)	2.6(6)	5.2(8)	1.9 (7)
1977*	4.4(10)	-	4.5(10)	-	4.9(9)	-
1978	4.7(8)	2.6(11)	4.6(11)	2.1(11)	5.1(10)	1.7(10)

S.D. - Secchi Disc Reading
Chl. a - Chlorophyll a Concentration

*Due to analytical problems, the 1977 chlorophyll a data was inaccurate, and therefore deleted.

(9) - number of measurements and/or analysis.

Table 3 summarizes the mean Secchi disc readings and chlorophyll a concentrations for Stations K39, K42 and K45, over the period 1975 to 1980. There is no distinct trend in the mean Secchi disc readings at these three stations. The chlorophyll a concentrations at Station K39 and K42, both located in Kempenfelt Bay, show a trend toward decreasing concentrations over this six year period. Caution, however, is required in drawing conclusions from these data, as the actual decreases in concentration is small, plus the number of samples taken each year and the time span over which they were taken varies.

The chlorophyll a concentrations at Station K45 show no specific trend.

Chapter Two

THE PHYTOPLANKTON OF LAKE SIMCOE, 1980

2.1 Abstract

Phytoplankton biomass and species composition demonstrate a clear gradient in trophic status through Lake Simcoe ranging from most enriched in southern Cook Bay to least enriched in the open waters of the main lake. Inner Kempenfelt Bay phytoplankton shows some influence of the nutrient inputs in this region. A clustering of phytoplankton similarlity coefficients demonstrates that the lake contains identifiable biocenoses with high percentage similarities linking sites located in proximity and/or in areas of the lake defined by similar conditions of nutrient status, water depth, optical properties, etc.

Calculations show the probable maximum "improvement" in trophic status of Cook Bay, after diversion of the two major municipal sewage sources out of the Lake Simcoe basin in 1983, will be a 0.3 mm^3/L decline in average May-October phytoplankton biomass and an increase in Secchi disc visibility of about one metre.

2.2 INTRODUCTION

Studies of the phytoplankton of lakes have demonstrated that information on the density and species composition of planktonic algae is most useful for trophic status assessment (Kalff and Knoechel, 1978; Willen, 1979) and long-term eutrophication trend analysis (Lund, 1973; Bailey-Watts, 1978; Holton, 1980; Nicholls, 1981).

Unfortunately, little is known of the phytoplankton-trophic state relationships of Lake Simcoe. Sparling and Nalewajko (1970) reported dominant species in a single sample collected near shore at Lefroy (Cook Bay) of Lake Simcoe in Novemer 1964. Nicholls (1976) reported phytoplankton composition and trophic state relationships for the lower Holland River (Holland Marsh), the major inflow to Cook Bay. Other data reported as total cell numbers of dominant classes of algae (Ontario Ministry of the Environment, 1975) are difficult to interpret owing to the great range in cell size among the common genera. It was suggested (Ontario Ministry of the Environment, 1975) that the trophic status of Lake Simcoe worsened during the late 1960's and early 1970's because conspicuous lake-wide surface accumulations of Anabaena and other bloom-forming blue-green algae were noted for the first time in 1971 and again in the late summer and fall of subsequent years.

This chapter of the Lake Simcoe report represents a new initiative by the Ontario Ministry of the Environment's Central Region and Limnology and Taxonomy Section to monitor the phytoplankton-trophic status components over the whole lake during the ice-free periods of the 1980's. These studies are especially critical at this time if a proper evaluation is to be made of Lake Simcoe's trophic state when industrial and residential growth within the basin is expanding and while programmes to decrease nutrient loading are being implemented. Most significant of the latter is the planned (1984) diversion of treated sewage from the municipalities of Newmarket and Aurora out of the Lake Simcoe Basin (C.C.R.D. 1979). In addition to phytoplankton and nutrient monitoring at several stations in the open lake, Kempenfelt and Cook Bays, monitoring at three municipal water intakes (Lagoon City, Beaverton and Sutton) were initiated in the fall of 1981 for more frequent year-round collection of near-shore water samples. Results from the intake programme will be reported separately.

2.3 METHODS

Phytoplankton samples were collected between May and October of 1980 at the nine stations established for nutrient and other limnological measurements (Fig. 1) by lowering and raising a tygon tubing through a water depth corresponding to 2.5X the Secchi disc visibility. Samples were fixed immediately after collection with Lugol's iodine solution. Analysis was as described in Nicholls and Carney (1979). The time period May 20 - September 23 was selected for statistical comparisons among the stations since some stations were not sampled before or after this period. Other details of data analysis are given at the appropriate places in the text.

2.4 RESULTS AND DISCUSSION

(a) Composition

Average phytoplankton biomass ranged from 1.58 mm^3/L at the south Cook Bay site (C1) to less than 0.6 at the open lake locations K45, E51 and E50 (Table 4). The greatest extremes of biomass were apparent during the late summer when average values for the July 21 - September 23 period of 1.73 and 1.1 mm^3/L at C1 and C6 in Cook Bay contrasted sharply with the very low biomass of 0.27 - 0.35 at Stations E50, E51 and K42 (Table 4).

The maximum phytoplankton biomass recorded was 7.4 mm^3/L at C1 on May 1 most of which (5.8 mm^3/L) was contributed by *Stephanodiscus* spp. The peak diatom biomass at the Kempenfelt Bay stations and at N31 occurred up to six weeks later. At all stations, much lower phytoplankton biomasses with negligible or minor contributions by diatoms characterized the mid-summer period (Figs. 19, 20, and 21). Other algal groups, notably the cryptomonads, dinoflagellates and green algae (Chlorophyceae) made significant contributions to total biomass at this time.

Table 4: Average total phytoplankton biomasses (mm^3/L) at the nine Lake Simcoe stations May 20-September 23, 1980 and divided into first half (May 23 - July 21) and second half (July 21 - September 23) time periods. Means underscored by the same line are not significantly different by analysis of variance and the least significant difference test (5% level).

	C1	C6	N31	C9	K39	K42	K45	E51	E50
May 20 - Sept. 23	1.58	1.23	0.94	0.90	0.83	0.69	0.58	0.51	0.50
May 20 - July 21	2.1	1.18	1.14	1.03	1.15	0.94	0.7	0.65	0.63
July 21 - Sept. 23	1.73	1.1	0.55	0.65	0.40	0.33	0.35	0.30	0.27

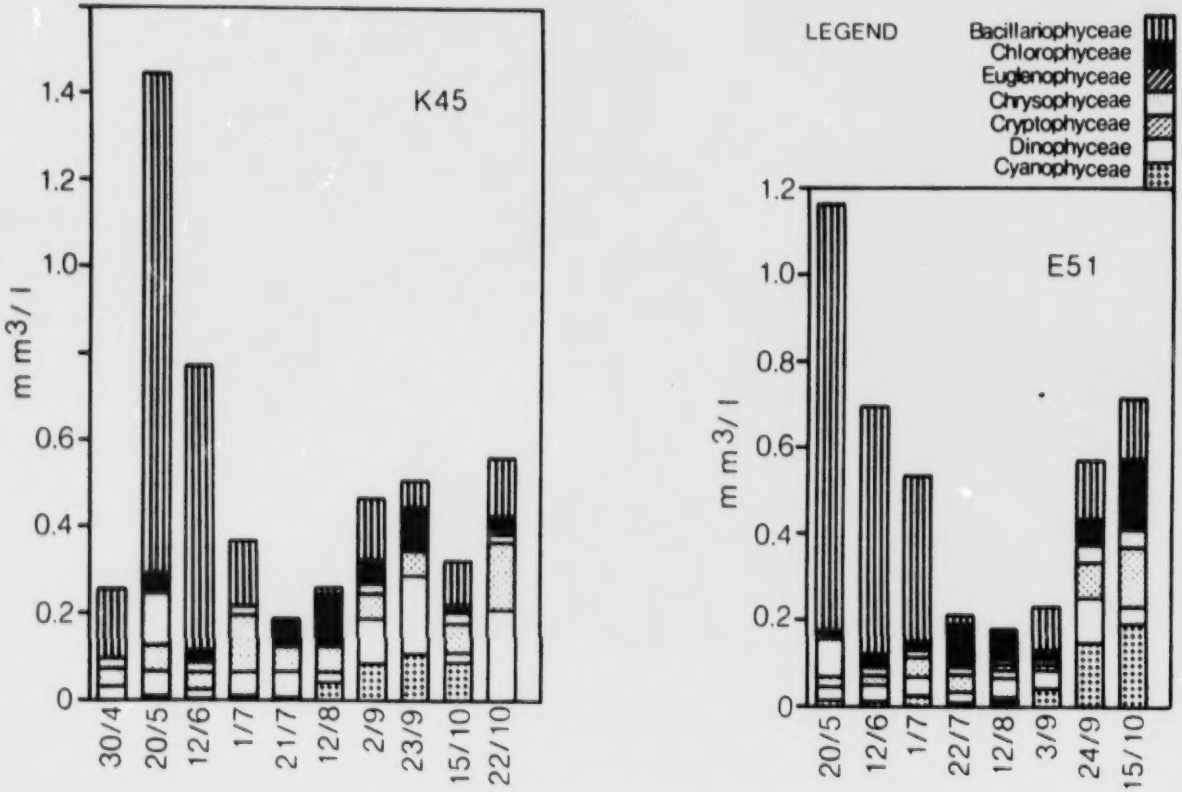


Fig. 19: Seasonal distribution of class densities at Stations K45 and E51.

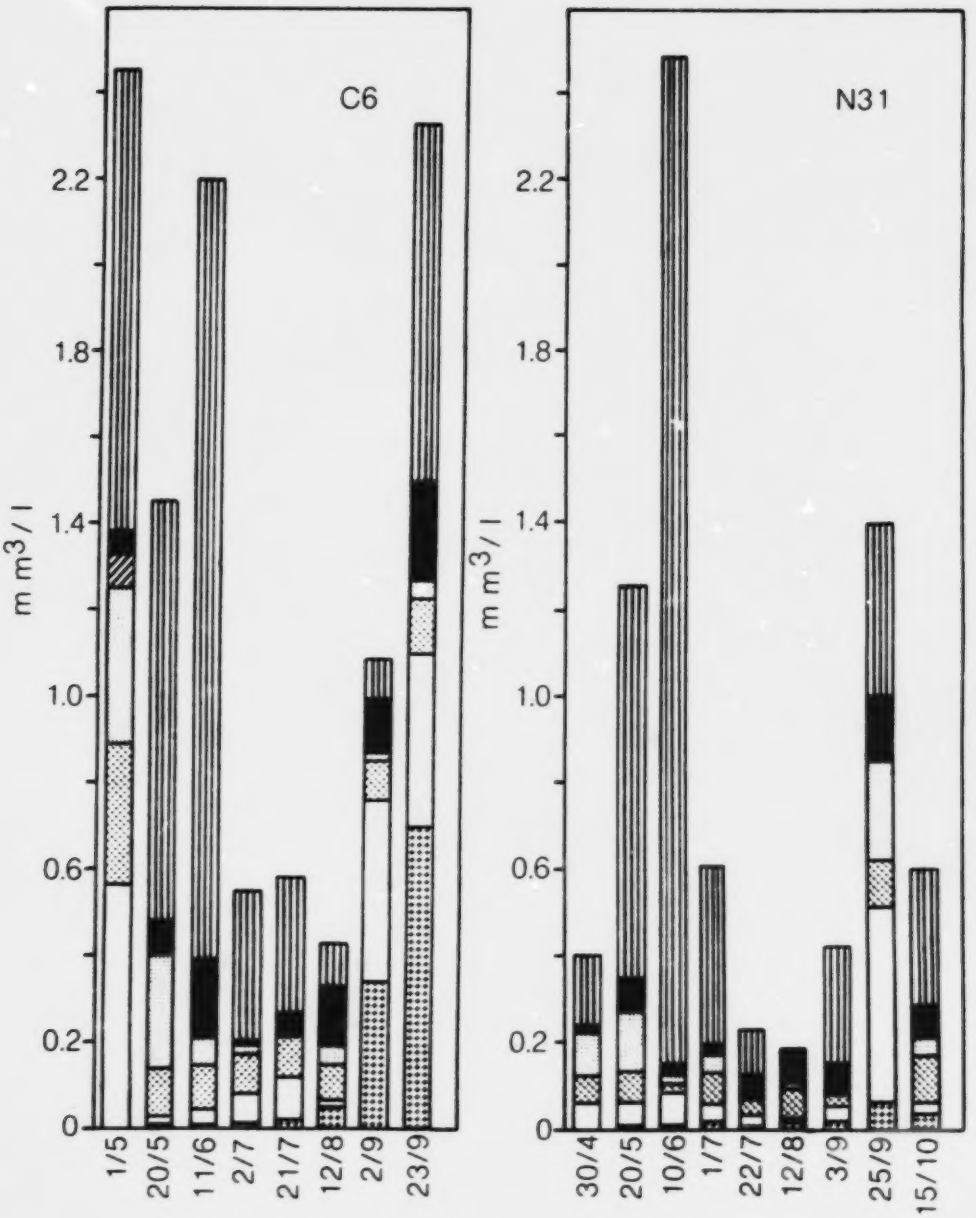


Fig. 20: Seasonal distribution of class densities at Stations C6 and N31. Keyed as in Fig. 19

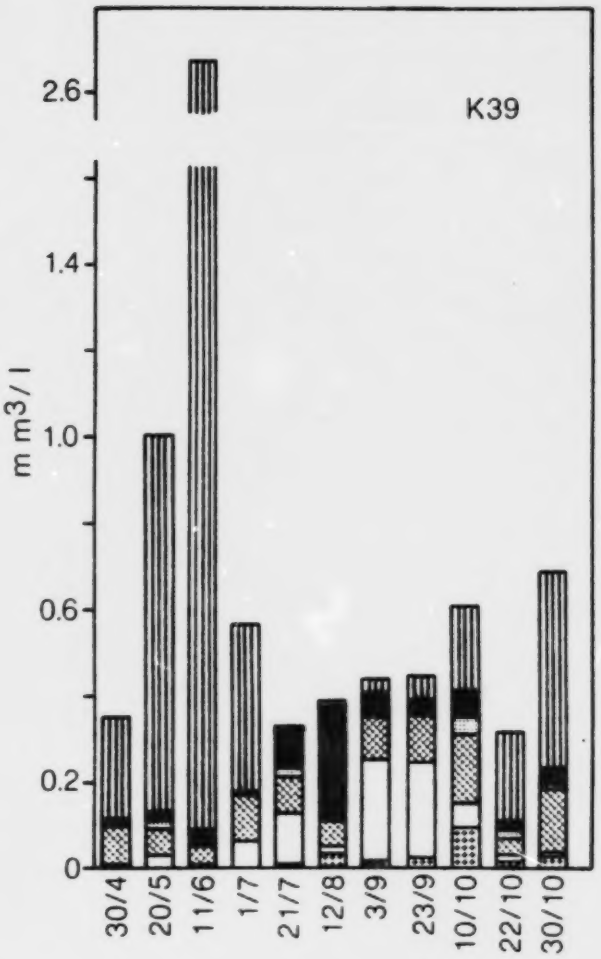


Fig. 21: Seasonal distribution of class densities at Station K39. Keyed as in Fig. 19.

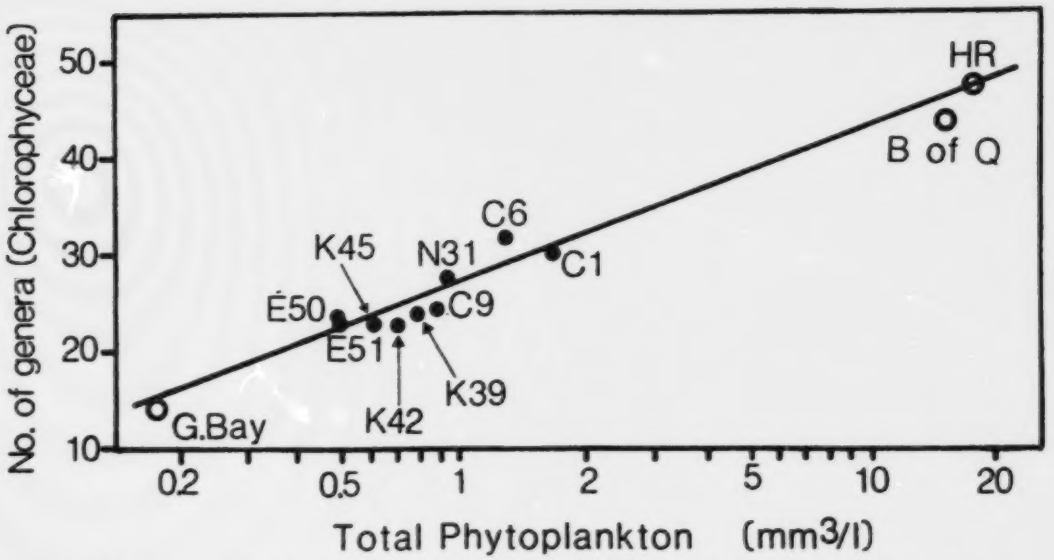


Fig. 22: The relationship between the average biomass of total phytoplankton (May-Oct.) and the number of genera of Chlorophyceae at the nine Lake Simcoe stations and three additional locations: HR, Holland River (Nicholls 1976); B of Q, Bay of Quinte, Station B (Nicholls and Carney 1979); G. Bay, Cape Rich area of Georgian Bay (O.M.E. unpublished).

Biomass increased again at all stations during September and October and Ceratium hirundinella, Stephanodiscus, Melosira and Cryptomonas spp. were common at most stations. The blue-green bloom forming species Anabaena flos-aquae was dominant throughout the lake during late summer and fall with highest densities found in Cook Bay during September (0.6 mm^3/L at C6).

Over the whole May 20 - September 23 period, the diatoms Bacillariophyceae) contributed between 50 and 70% of the total phytoplankton biomass. Next in importance were the dinoflagellates (Dinophyceae), green algae (Chlorophyceae) and cryptomonads (Cryptophyceae) with average constributions of 6-20% (Fig. 23). The Chrysophyceae, mainly Dinobryon and Mallomonas spp., and Cyanophyceae (mainly Anabaena, Aphanizomenon, Coelosphaerium, Lyngbya and Oscillatoria spp.) contributed minimally (<5%) to the total at most stations. Englenophyceae (Euglena, Phacus and Trachelomonas spp.) averaged less than 1% of total biomass, although on May 1 Euglenophyceae were relatively high at 0.04 and 0.08 mm^3/L at C1 and C6, respectively.

Based on average class density over the May 20 to September 23 period, it is apparent from a clustering of percentage similarities (Fig. 24) that stations situated in embayments and in similar conditions of trophic state, water depth, exposure, etc. show the highest degree of similarity of phytoplankton composition. For example, the Kempenfelt Bay staions K39 and K42 are much more similar to each other (91%) than either of them is to any other station or group of stations. Similarly, Stations E50 and E51 and C6 and C9 are very similar pairs of stations, related at similarity values of 92 and 96%, respectively. Station N31 compares best with a group of stations (E50, E51, C6 C9 and K45) at a much lower level of similarity. Station C1 is likely influenced considerably by the Holland River and hence shows the greatest degree of dissimilarity to all other stations (Fig. 24).

mm^3 / l	C1	C6	C9	N31	E50	E51	K39	K42	K45
Cyanophyceae	92	118	73	18	34	36	13	16	39
Dinophyceae	120	149	149	103	44	44	103	70	78
Cryptophyceae	92	101	85	57	37	37	72	68	62
Chrysophyceae	75	62	54	66	27	34	10	16	26
Euglenophyceae	8	0	0	0	0	0.8	0	0	0
Chlorophyceae	282	118	70	67	42	43	69	56	58
Bacillariophyceae	910	635	471	633	312	315	563	457	311

% of total	C1	C6	C9	N31	E50	E51	K39	K42	K45
Cyanophyceae	·	•	•	·	•	•	·	·	•
Dinophyceae	•	●	●	•	•	•	●	•	●
Cryptophyceae	·	•	•	•	•	•	•	•	•
Chrysophyceae	·	·	•	•	·	•	·	·	·
Euglenophyceae									
Chlorophyceae	•	•	•	•	•	•	•	•	•
Bacillariophyceae	●	●	●	●	●	●	●	●	●

LEGEND

	< 1 %	•	21 - 35 %
·	1 - 5 %	●	36 - 49 %
•	6 - 10 %	●	50 - 59 %
•	11 - 20 %	●	60 - 70 %

Fig. 23: Primary matrix of average class densities (upper) at the nine Lake Simcoe stations, May 20-Sept. 23, 1980 and percentage of total phytoplankton biomass (lower).

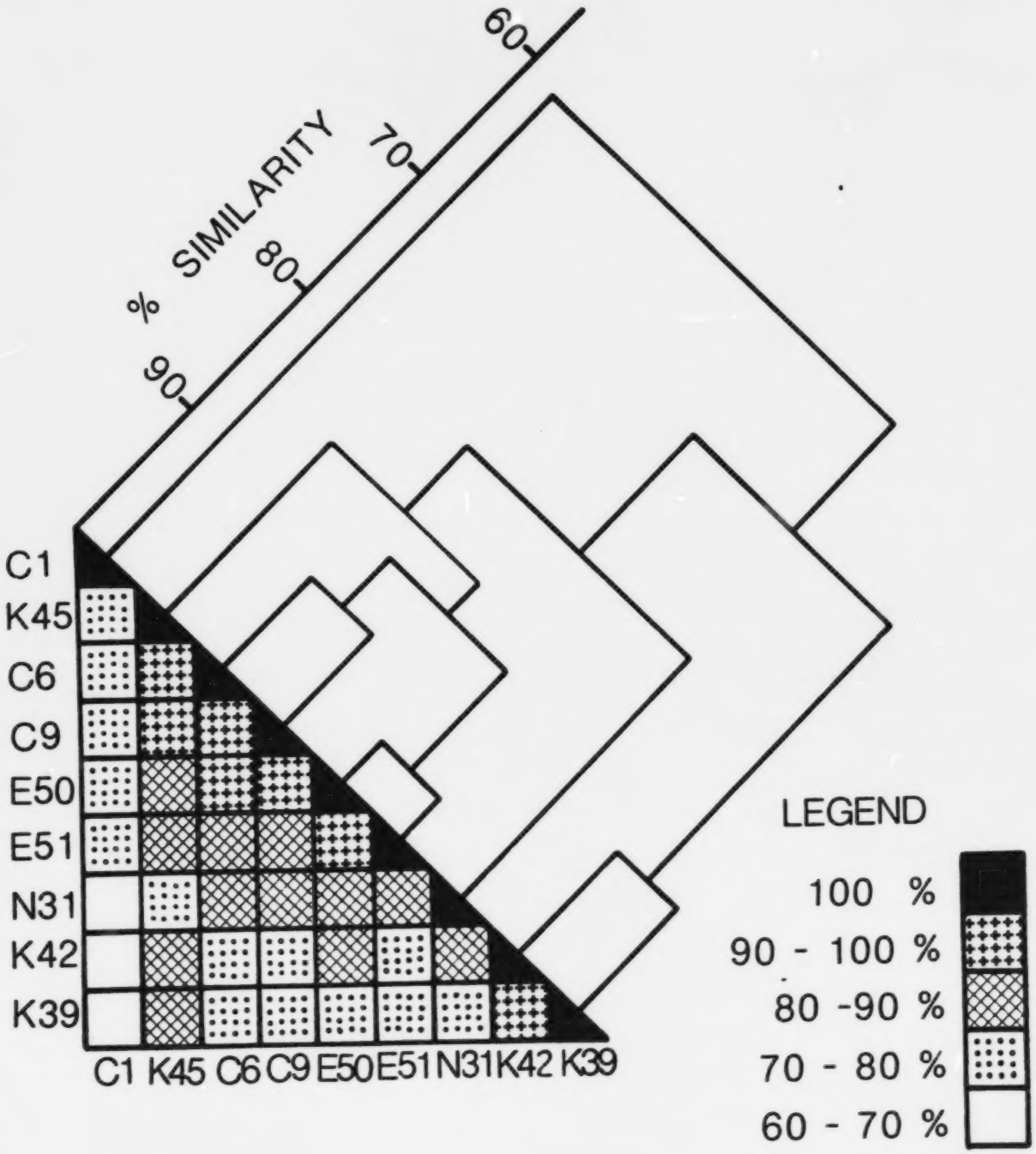


Fig. 24: Matrix and dendrogram of percentage similarities of average class density at the nine Lake Simcoe stations May 20-Sept.23, 1980. Values were calculated after double standardization (Cottam et al. 1973) of a primary matrix (Fig. 23). Criteria for clustering followed Sorensen's (1948) method for complete linkage.

(b) Trophic Status

Most assessments of phytoplankton relative to lake trophic status have considered only total biomass and not enough attention has been paid to "indicator" species or other taxonomic groupings which characterize oligotrophic and eutrophic lakes. Davis (1964) and Hohn (1969) related changes in the diatom community in Lake Erie to accelerated eutrophication between 1930 and 1960. Other examples of the use of phytoplankton data in this way are scarce (e.g. Hickel 1975; Stoermer 1978) probably because few long-term data sets are available.

In Ontario lakes, the diversity or richness of the Chlorophyceae is directly related to phytoplankton biomass (unpub. data). The most eutrophic lakes with high average phytoplankton biomass are also characterized by many more green algal genera than found in oligotrophic waters; this is true of Lake Simcoe as well (Fig. 22). Of the Chlorphyceae, several of the chlorococcalean species appear to have high nutrient demands. Scenedesmus spp. in particular are characteristic of fertilized fish ponds and highly eutrophic waters. The Cook Bay stations showed the highest densitities of Scenedesmus and Station K45, the lowest (Fig. 25).

Several other algal species such as the eutrophic indicators Ceratium hirundinella, Anabaena, Aphanizomenon and Pediastrum species, Melosira granulata, M. ambigua, Stephanodiscus hantzschii and S. astraea now appear to be firmly established in parts or all of Lake Simcoe. Similarly, what appear to be remnant populations indicative of oligotrophy (e.g. some species of Cyclotella, Bicosoeca, Bitrichia, Chrysolykos and Kephyrion), are also present in the open waters of the lake and continued monitoring of both groups will be instructive for trophic status trend analysis.

It is generally widely accepted that phosphorus and nitrogen are key elements controlling phytoplankton growth, but for

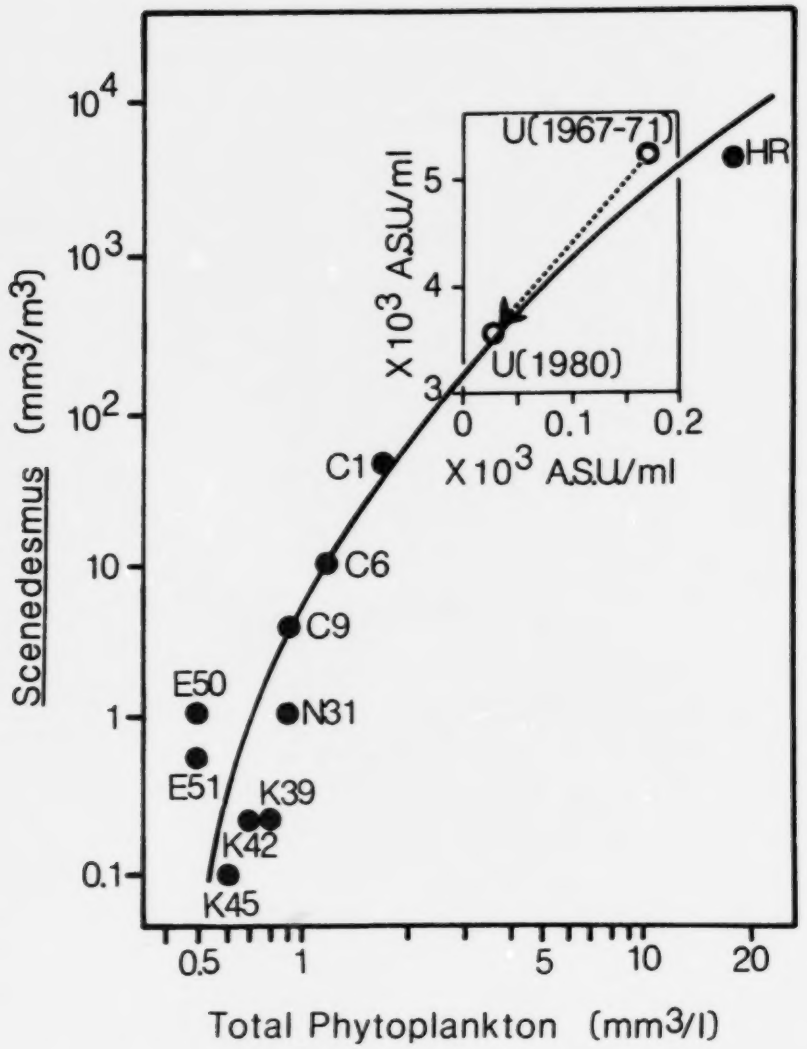


Fig 25: Relationship between average May-Oct biomass of Scenedesmus spp. and total phytoplankton biomass at the nine Lake Simcoe stations. Also shown are data for the Holland River, HR (Nicholls 1976) and for the Union water intake at Kingsville in western Lake Erie (U) showing the response to phosphorus loading controls (Nicholls et al. 1980 and unpublished).

reasons related to atmospheric N fixation by certain algae and technical difficulties in reducing N at point sources, phosphorus control is necessary to reverse eutrophication tendencies in lakes (Vollenweider, 1968; Vallentyne et al., 1970; Schindler, 1977). In Lake Simcoe, statistically significant correlations between average phytoplankton biomass and total P, total N and N/P were found (Fig. 26). The lowest N-to-P ratios were found in southern Cook Bay and inner Kempenfelt Bay (Fig. 26), two areas receiving important point source inputs of nutrients. It is these areas which are likely to respond first to controls on P loading from municipal sewage treatment plants and intensively cultivated muckland (Nicholls and MacCrimmon, 1975).

Based on phytoplankton, Secchi disc and total P data, Cook Bay might be considered mesotrophic while the other Lake Simcoe stations are oligotrophic (Fig. 27). The position of Lake Simcoe on these plots (Fig. 27) is useful for comparison with other sites along the Trent-Severn waterway of which Lake Simcoe is a part; however, it should be noted that these data do not include the late April-early May results in the calculated means and at some stations where results from the early sampling dates are available, phytoplankton biomass, Secchi disc recriprocal and total P values are much higher than at any other time in the sampling period and would alter the trophic status assessment (relative to Fig. 27) if they were included.

Nicholls and MacCrimmon (1975) considered Cook Bay as highly eutrophic. Their assessment, based only on estimated N and P loadings and mean depth, can be made more meaningful by inclusion of estimates of flushing rate and P retention (Vollenweider 1969, 1975; Dillon 1975). The "Vollenweider model" with various modifications (Dillon and Rigler 1974; Ostrofy 1978; Osborne 1980; Canfield & Bachmann 1981) has been used to predict P concentrations in lakewater. In view of the anticipated decrease in nutrient loading to Cook Bay resulting from the future diversion (1983) of treated sewage from the municipalities of Newmarket and Aurora to the

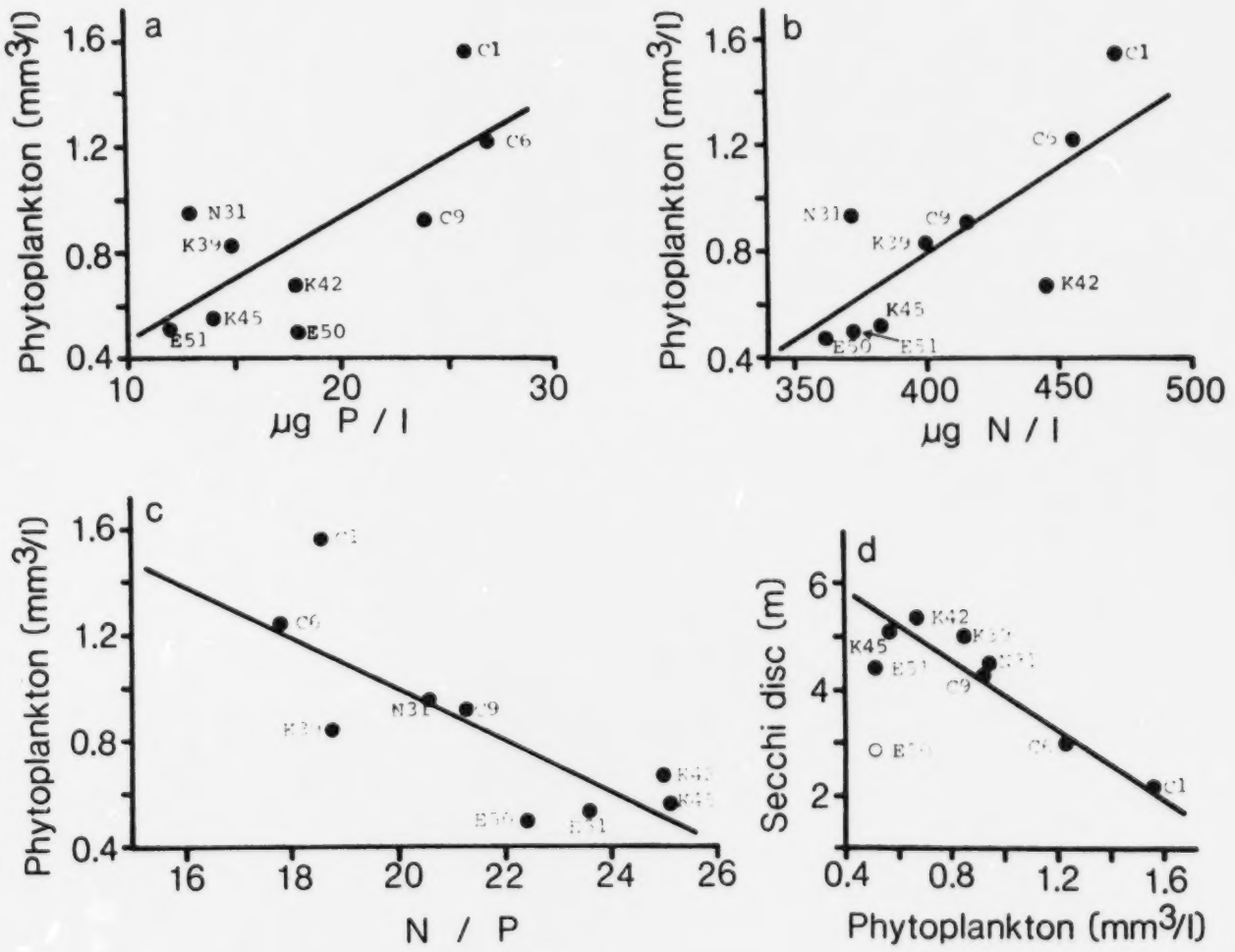


Fig. 26: Relationships between average phytoplankton biomass and average total P, total N, total N-to-toal P ratios and secchi disc visibilities at the nine Lake Simcoe stations, May 20 - Sept. 23, 1980. Secchi disc data for E50 were not included in the regression analysis (see text). Total P and N/P averages excluded the July 21, 22 dates when anomalously high values of total P were recorded. Regression coefficients for figs. a, b, c and d are 0.74, 0.73, -0.77 and -0.89; all are statistically significant at $\leq$ 0.05.

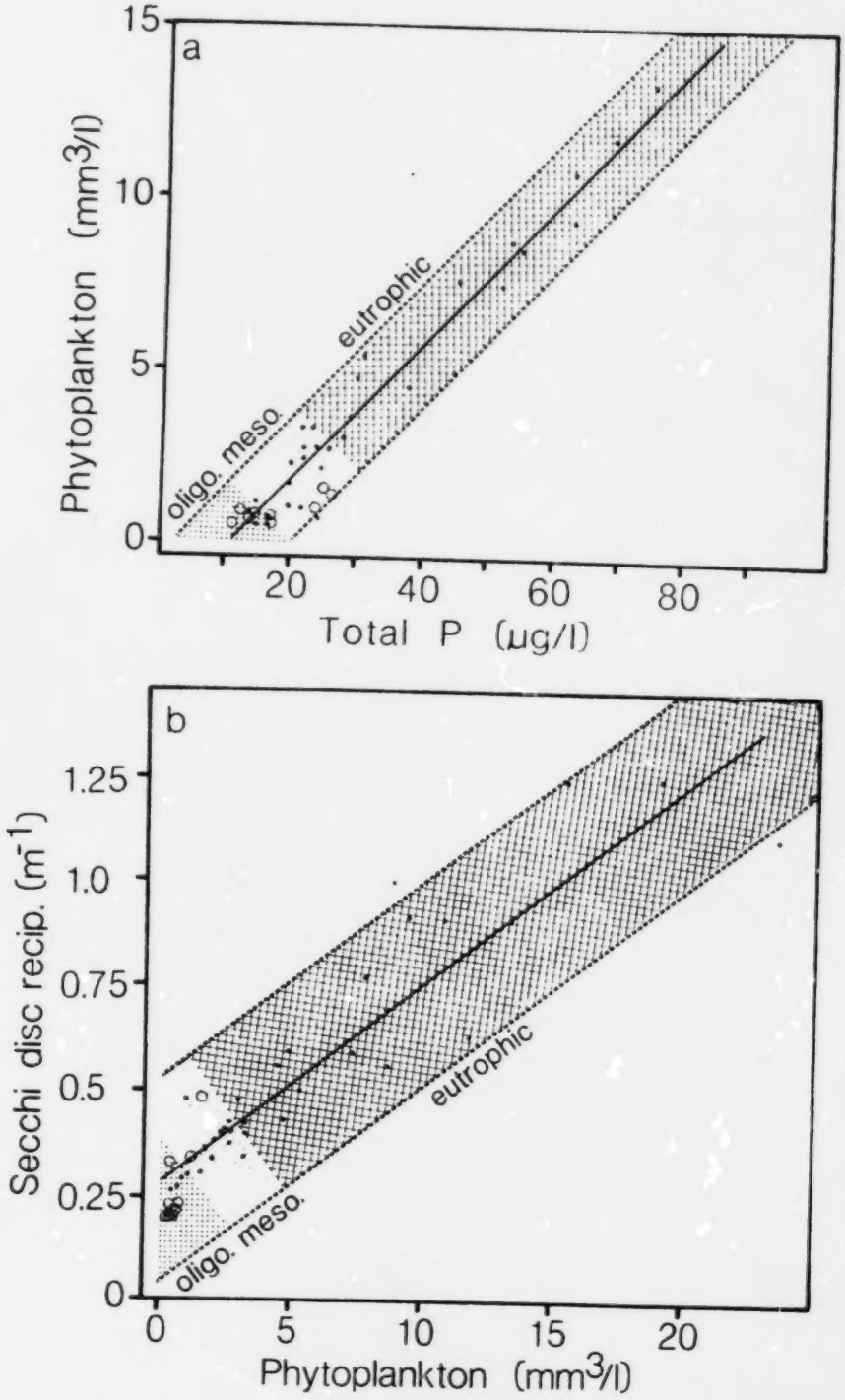


Fig. 27(a): Regression of average (May-Oct) phytoplankton biomass on total phosphorus and (b) Secchi disc reciprocal on total phytoplankton biomass in the Kawartha-Trent-Quinte system (data from Nicholls and Dillon, 1978) showing the 95% confidence interval for prediction of "Y" from "X". The nine Lake Simcoe stations (open circles) are shown in the oligo-mesotrophic range.

York-Durham sewage treatment facilities which are outside the Lake Simcoe basin (C.C.R.D. 1979), it is instructive to attempt some predictions of change in trophic state of Cook Bay resulting from the projected decrease in P loading.

The P load to Cook Bay does not change in direct proportion to the water load during the year because the municipal point sources constitute a higher proportion of the total P input during summer when land drainage inputs of P and total water loads are much lower than the seasonal highs during early spring and fall. The four conditions of the Vollenweider model (Osborne 1980) are therefore not violated the summer period, when the loading rate is relatively constant, is used for predictive purposes (recognizing also that most of Cook Bay is shallow and well mixed during this period (Ontario Ministry of the Environment, 1975). The basin areas, hydrology, atmospheric P loading and estimates of P loading from land drainage excluding the Holland River were taken from Nicholls and MacCrimmon (1975) and altered to represent the May to October period only (Table 2). These alterations assume that land drainage export of P varies directly with runoff (Johnson and Owen, 1971) and that approximately 25% of the annual runoff occurs during the May to October period (Coulson 1967). The May-October loading from the Holland River was estimated by integrating monthly average total P measured in the lower river (Coulson 1967; Nicholls and MacCrimmon 1975).

Assuming $[P] = \frac{L(1-R)}{z \cdot \rho}$. (Dillon and Rigler 1974) and [P] = 27 mg/m^3 (average of six euphotic zone composite samples collected between 20 May and 23 September, 1980), ρ (the May-October flushing rate) = 0.23 and L = 266 mg P/m^2 (Table 5), therefore R (the retention coefficient) = 0.85. The diversion of the P loading from both the Aurora and Newmarket sewage treatment plants gives a projected reduction of approximately 6 metric T P/y to the Holland River (C.C.R.D. 1979) or approximately 2.3T during the May-October period. The new May-October loading to Cook Bay then becomes 191 mg

Table 5: Morphometric data for Cook Bay and its drainage basin and estimates of May to October total phosphorus loading

Cook Bay			Drainage Basin Area (m^2)		P Loading, May-October (metric T)		
Area (m^2)	Vol. (m^3)	$\bar{Z}$(m)	Holland River	Remainder	Holland River	Remainder[1]	Precipitation
3.04×10^7	1.92×10^8	6.3	6.01×10^8	1.02×10^8	6	1.2	0.9

[1] The total P export value of 0.5 kg P/ha·y for "mixed agricultural-urban" is higher than the 0.3 kg P/ha.y determined for "mixed agricultural-woodland" (Nicholls and MacCrimmon 1975) and was used for the remainder of the Cook Bay catchment outside of the Holland River basin because this area included shorline cottage development around Cook Bay for which separate estimates of P loss to the lake from septic tank-tile beds were not available.

JD/ns/REPT 8-Q

P/m^2 (assuming a P reduction of equal magnitude at the river mouth as at the upstream point source) and the new [P] in Cook Bay (May-October average) becomes 19 mg/m^3, i.e. a reduction of 8 mg/m^3. From Fig. 26 this reduction in average P concentration should be associated with a reduction in average phytoplankton biomass of approximately 0.3 mm^3/L and an increase in Secchi disc visibility of about 1m.

These calculations assume that the relative importance of water exchange between the open lake and Cook Bay will not change drastically after the reduction in Cook Bay P loading. There are no apparent reasons to expect that it will change beyond those year-to-year changes brought about by different weather conditions. Also, it is clear that the net movement of water is out of Cook Bay during summer since the water level in Lake Simcoe is controlled to a large extent and is lowered on average 0.35m over the May to October period (Parks Canada,1980).

The municipal P loadings from Newmarket and Aurora are presently discharged to the Holland River 20-25 km upstream from Cook Bay. It is not known whether a reduction of 2.3T at the discharge sites will achieve a similar reduction at Cook Bay since little is known of P fluxes in the lower river. Nicholls and MacCrimmon (1975) calculated that the lower Holland River was a sink for 16% of the annual P export from the watershed but suggested that the same section of river might be a significant source of P during stagnant mid-summer conditions when concentrations of dissolved reactive P in the lower 5 km of the river increased to between 0.4 and 0.7 mg P/L. The diversion of sewage from Newmarket and Aurora out of the Cook Bay drainage basin may therefore not have as dramatic an effect on Cook Bay phytoplankton density and water clarity as the above calculations might suggest. Nevertheless, the calculations are useful in that they illustrate the maximum improvement in the trophic status which can be expected from the planned sewage diversion.

REFERENCES CITED

BAILEY-WATTS, A.E. 1978. A nine-year study of the phytoplankton of the eutrophic and non-stratifying Loch Level (Kinross, Scotland). J. Ecol. 66:741-771.

CANFIELD, D.E. and R.W. BACHMANN. 1981. Prediction of total phosphorus concentrations, chlorophyll a and Secchi depths in natural and artificial lakes, Can. J. Fish. Aquat. Sci. 38:414-423.

C.C.R.D. 1979. Prov. of Ontario Cabinet Committee for Resources Development. Information for meeting with the Lake Simcoe - Couchiching Steering Committee. Nov. 1, 1979, 2p. Toronto.

COTTAM, G., F.G. GOFF and R.H. WHITTAKER. 1973. Wisconsin comparative ordination. In R.H. Whittaker [ed.] Handbook of Vegetation Science Part V, Ordination and Classification of Communities. Dr. W. Junk, The Hague.

COULSON, A. 1967. Estimating runoff in southern Ontario. Dept. of Energy, Mines and Resources. Tech. Bull. No. 7, 19p. Ottawa.

DAVIS, C.C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. Limnol. Oceanogr. 9:275-283.

DILLON, P.J. 1975. The phosphorus budget of Cameron Lake, Ontario: The importance of flushing rate to the degree of eutrophy in lakes. Limnol. Oceanogr. 20:28-39.

DILLON, P.J. and F.H. RIGLER. 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. J. Fish. Res. Board Can. 31:1771-1778.

HICKEL, B. 1975. Changes in the phytoplankton species composition since 1894 in two lakes of East-Holstein, Germany, Verh. Internat. Verein. Limnol. 19:1229-1240.

HOHN, M.H. 1969. Qualitative and quantitative analysis of plankton diatoms, Bass Island Area, Lake Erie, 1938-1965 including synoptic surveys of 1960-1963. Bull. Ohi Biol. Survey (N.S.), 3:1-211.

HOLTAN, H. 1980. The case of Lake Mjøsa. Prog. Wat. Tech. 12:103-120.

JOHNSON, M.G. and G.E. OWEN. 1971. Nutrients and nutrient budgets in the Bay of Quinte, Lake Ontario. J. Water Poll. Control Fed. 43:836-853.

KALFF, J. and R. KNOECHEL. 1978. Phytoplankton and their dynamics in oligotrophic and eutrophic lakes. Ann. Rev. Ecol. Syst. 9:475-495.

LUND, J.W.G. 1973. Changes in the biomass of blue-green and other algae in an English lake from 1945-69, pp. 305-327. In T.V. Desikachary [ed.], Taxonomy and Biology of Blue-Green Algae. Madras Symposium, University of Madras, 1970.

NICHOLLS, K.H. 1976. Nutrient-phytoplankton relationships in the Holland Marsh, Ontario. Ecol. Monogr. 46:179-199.

_____ 1981. Recent changes in the phytoplankton of lakes Erie and Ontario. Proc. Conf. on Changes in the Biota of Lakes Erie and Ontario. Bull. Buff. Sco. Nat. Sci. 25:41-88.

_____ and H.R. MACCRIMMON. 1975. Nutrient loading to Cook Bay of Lake Simcoe from the Holland River watershed. Int. Revue. ges. Hydrobiol. 60:159-193.

_____ and P.J. DILLON. 1978. An evaluation of phosphorus-chlorophyll-phytoplankton relationship for lakes. Int. Revue ges. Hydrobiol. 63:141-154.

_____ and E.C. CARNEY. 1979. The Taxonomy of Bay of Qunte phytoplankton and the relative importance of common and rare taxa. Can. J. Bot. 57:1591-1608.

_____, D.W. STANDEN and G.J. HOPKINS. 1980. Recent changes in the near-shore phytoplankton of Lake Erie's western basin at Kingsville, Ontario. J. Great Lakes Res. 6:146-153.

ONTARIO MINISTRY OF THE ENVIRONMENT. 1975. Lake Simcoe Basin, a Water Quality and Use Study. Ontario Ministry of the Environment. June 1975, Toronto. 143 p.

OSBORNE, P.L. 1980. Prediction of phosphorus and nitrogen concentrations in lakes from both internal and external loading rates. Hydrobiol. 69:229-233.

OSTROFSKY, M.L. 1978. Modification of phosphorus retention models for use with lakes with low areal water loading. J. Fish. Res. Board Can. 35:1532-1536.

PARKS CANADA. 1980. Trent-Severn Waterway, Severn Division 1980. Lake Simcoe-Severn Water Reg'n Chart C-6-3000-AB. Peterborough.

SCHINDLER, D.W. 1977. The evaluation of phosphorus limitation in lakes. Science 195:260-262.

SORENSEN, T. 1948. A method for establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. K. Dansk. Vidensk. Selsk. Biol. Skrift. 5:3-16.

SPARLING, J.H. and C. NALEWAJKO. 1970. Chemical composition and phytoplankton of lakes in southern Ontario. J. Fish. Res. Board Can. 27-1405-1428.

STOERMER, E.F. 1978. Phytoplankton assemblages as indicators of water quality in the Laurentian Great Lakes. Trans. Amer. Micros. Soc. 97:2-2-16.

VALLENTYNE, J.R., W.E. JOHNSON and A.J. HARRIS. 1970. A visual demonstration of the beneficial effects of sewage treatment for phosphate removal on particulate matter production in waters of lakes Erie and Ontario. J. Fish. Res. Board Can. 27:1493-1496.

VOLLENWEIDER, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. O.E.C.D. DAS/CSI/68, Paris. Vol. 27:159p.

_____ 1969. Moglichkeiten und Grenzen elementaser Modelle der Stoffbilanz von Seen. Arch. Hydrobiol. 66:1-36.

_____ 1975. Input-output models. Schwiez. Z. Hydrol. 37:53-84.

WILLEN, T. 1979. Phytoplankton as a criterion of water quality. Acta Bot. Fennica 110:47-52.

Chapter Three

CLADOPHORA IN LAKE SIMOE 1976 and 1980

3.1 ABSTRACT

Factors affecting the periodicity of Cladophora standing crop at a nutrient enriched nearshore site in Lake Simcoe are examined. These data are compared with observations from similar investigations in the Great Lakes. Cladophora is used to assess site-to-site differences in the bioavailability of selected nutrients and heavy metals as evidence of local sources.

3.2 INTRODUCTION

Cladophora is an attached filamentous green alga (Chlorophyceae) which grows in wave-washed nearshore waters of large alkaline lakes. In the Great Lakes, excessive proliferation of *Cladophora* is considered to be a major symptom of eutrophication (Shear and Konasewich 1975). Lakes Erie and Ontario, in particular, have a long history of water use problems relating to the widespread growth and decomposition of *Cladophora*. In the Upper Great Lakes, background phosphorus concentrations are too low to support basinwide growth and *Cladophora* is a problem only in association with local nutrient sources (Herbst 1969, Lin 1971, Neil and Owen 1964). Recent investigations in Lake Huron and Georgian Bay have resulted in the development of biomass models to evaluate the impact of various phosphorus management strategies on *Cladophora* growth (Auer *et al*. 1980, Jackson and Hamdy 1982).

Like many aquatic plants, *Cladophora* accumulates chemical elements from its external environment reflecting a time integration of bioavailable external supply (Keeney 1976). This has practical applications to monitoring nearshore water quality. For example, since *Cladophora* growth rate is proportional to internal phosphorus concentration (Auer and Canale 1980), monitoring this internal nutrient is an effective way to measure the biological significance of phosphorus control programs. Similarly, the bioavailability of certain heavy metals can be monitored with good resolution internally, even though external concentrations are undetectable.

The purpose of this investigation is to document and interpret data collected in 1976 and 1980 on nearshore *Cladophora* growth, nutrient status and lead and mercury levels in nearshore Lake Simcoe.

3.3 MATERIALS AND METHODS

In 1976, field sampling was carried out weekly from June through mid-November in Lake Simcoe at nine sites on the west shore and from mid-August through mid-November at nine sites on the east shore (Figure 28, Table 6). In 1980, sampling frequency was about once every two weeks from late may through October at eight shoreline sites. In general, sites were selected to contrast locations 'affected' by and 'remote' from inflows and urban-industrial areas. At each site, surface water temperature was recorded and water samples were collected for analysis of total and soluble reactive phosphorus, free ammonia, nitrite, nitrate and total Kjeldahl nitrogen. Cladophora biomass was collected from the 0-0.5 m depth zone for determination of internal total phosphorus and nitrogen levels and, in 1980, biomass was also collected for determination of internal total mercury and lead concentrations. At KI, in 1976, Cladophora standing crop determinations were collected in triplicate at depths of 0.5 m and 1.0 m using a 0.25 m^2 sampling quadrat. All biomass samples were rinsed with ambient water, patted dry, wrapped in absorbant paper and transported on-ice to the O.M.E. laboratory in Rexdale, Ontario. Relevant biological and chemical analytical procedures are described in O.M.E. (1981). S.P.S.S. (Nie et al. 1975) was used to generate descriptive statistics (Subprogram Condescriptive) and to perform regression (Subprogram Regression) and discriminant (Subprogram Discriminant) analyses.

3.4 RESULTS

(a) Cladophora Growth

(i) Periodicity

The exposed and gently sloping cobblestone beach at KI located just east of the Orillia sewage treatment plant outfall is the only known location in Lake Simcoe where Cladophora biomass reached problematic proportions each summer (Table 7). The following observations describe the seasonal

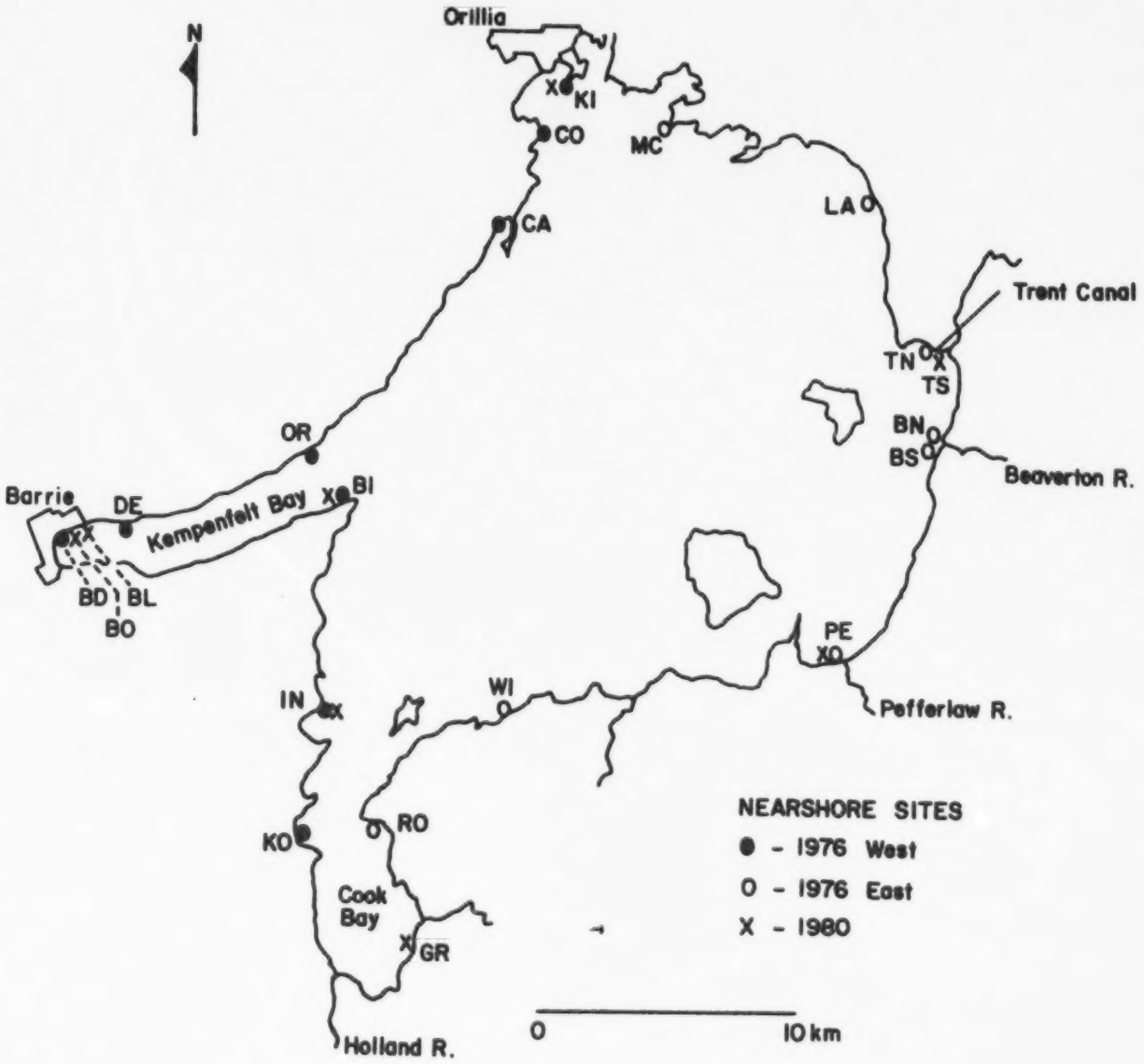


Figure 28: Nearshore sites in Lake Simcoe, 1976 and 1980.

Table 6: Nearshore site descriptions in Lake Simcoe, 1976 and 1980. An asterisk (*) identifies sites considered 'affected' by inflows or urban-industrial areas while the remaining sites are 'remote' from any apparent impact.

		Sampling			
Year	Shore	Frequency	Duration	Site	Comments
1976	West	Weekly	June-mid-November	*KO	Rocks in front of Kantiki Marina near Holland River inflow
				IN	Rocks on south side of public dock at Innisfil beach
				BI	Rocks on east and west sides of public dock at Big Bay Point
				*BD	Cement rubble on west side of public dock in Barrie
				*DE	Cement rubble by storm sewer outfall at Deep Point Park
				OR	Natural cobble at foot of concession road south of Oro Park
				CA	Rocks on north and south sides of public dock at Carthew Bay
				CO	Rocks on north and south sides of cement dock near Columbus Boys Camp
				*KI	Natural cobble at Kitchener Park east of Orillia STP outfall
1976	East	Weekly	Mid-Aug.-mid-Nov.	MC	Cement/rock rubble around boat launch at McRae Provincial Park
				LC	Rocks at foot of concession road south of Lagoon City
				*TN	Rocks outside north breakwall at Trent Canal
				*BN	Rocks cutside north breakwall at Beaverton River
				*BS	Rocks outside south breakwall at Beaverton River
				*PE	Rocks outside south breakwall at Pefferlaw River
				WI	Rocks on east and west sides of public dock at Willow Beach
				*RO	Rocks on east side of public dock at Roches Point near Holland River inflow
1980	W/E	Biweekly	Late May - Oct.	*GR	Rocks at foot of Glenwood Road near Holland River inflow
				IN	See 1976
				BI	See 1976
				*BO	Cement rubble on east side of public dock by storm sewer outfall in Barrie
				*BL	Cement rubble 75 m east of BO
				*KI	See 1976
				*TS	Rocks outside south breakwall at Trent Canal
				*PE	See 1976

ns/REPT 10-C-1

Table 7: Cladophora standing crop at 0.5 m and 1.0 m depths at KI in Lake Simcoe, 1976.

Date	Standing Crop (g DW/m²)	
	0.5 m	1.0 m
June 17	142	228
24	604	284
29	251	306
July 8	288	196
15	196	-
22	440	-
29	166	143
Aug 5	222	86
11	380	237
19	384	284
26	620	343
Sept 2	195	126
9	245	58
16	271	82
23	137	-
30	159	-
Oct 7	154	-
14	102	-
21	105	-

REPT 10-B-1

pattern of Cladophora growth at KI in 1976. These observations refer only to the submerged form of Cladophora, although, a fringing waterline growth is common in Lake Simcoe from mid-July through to freeze-up (for further details on the fringing growth form of Cladophora see Taft and Kischler 1973).

Cladophora was first noted on June 3; coverage was patchy at depths shallower than 0.5 m, while a uniform mat of filaments, 5-10 cm long, covered all substrate at greater depths. Conditions were much the same on June 10 when growth was most abundant at 1.0 - 1.5 m depth and sparse coverage was observed to 3 m depth. By June 17, Cladophora filaments were notably dark green and healthy-looking and initial measurements of standing crop at 0.5 m and 1.0 m depths were 144 g DW/m^2 and 228 g DW/m^2. The first Cladophora 'bloom' was recorded on June 24 in the 0.5 m depth zone and accumulation of biomass was so great that ropes of filaments reached the water surface over much of the study area. Standing crop determinations at 0.5 m depth had increased about fivefold to 604 g DW/m^2 in one week; however, a similar increase was not recorded at the 1.0 m sample depth.

By June 29, most of the Cladophora biomass accumulated in the 0.5 m depth zone had been sloughed and driven ashore by wave action. During the remainder of the 1976 summer period there were two more instances of excessive proliferation and sloughing of Cladophora biomass in the 0.5 m depth zone. The first event occurred in mid-July and the second in late August and by mid-September active growth below the waterline appeared to have terminated. Peak standing crop values at 1.0 m depth were always considerably less than at 0.5 m depth, although at each depth, the frequency of peak biomass occurrences was the same.

(ii) Controlling Factors

Figure 29 illustrates the week-to-week changes in Cladophora standing crop in relation to some possible growth controlling factors at KI in 1976. Peaks in standing crop in June, July and August are preceeded by a period of a week or more of reduced water temperatures, high levels of internal total phosphorus and nitrogen and high internal N:P ratios. Attainment of peak standing crop values coincide with maximum water temperatures, severely depleted internal nutrient concentrations and much reduced internal N:P ratios.

Table 8 lists a matrix of simple correlation coefficients between Cladophora standing crop at 0.5 m depth and each of the growth controlling factors for the period June 17 through September 16. Standing crop is significantly correlated with both temperature ($R = 0.76$, $P < 0.01$) and internal total nitrogen ($R = 0.70$, $P < 0.01$). Temperature, internal total nitogen and phosphorus are all significantly intercorrelated ($P < 0.05$). Only internal N:P is not significantly correlated with any of the other variables ($P > 0.05$).

The results of stepwise multiple regression analysis, for the same period, confirm that temperature is the most important predictor of biomass response since it alone explains 58 % of the week-to-week variability in Cladophora standing crop at 0.5 m depth (Table 9). Internal N:P explains an additional 13 % of the variability in standing crop. Although, internal total phosphorus and nitrogen concentrations are not individually significant in the multiple regression analysis (probably because of significant intercorrelation among themselves and with temperature), their combined effect is significant through the ratio variable, internal N:P. The following equation describes the relationship between standing crop at 0.5 m depth and the significant independent variables,

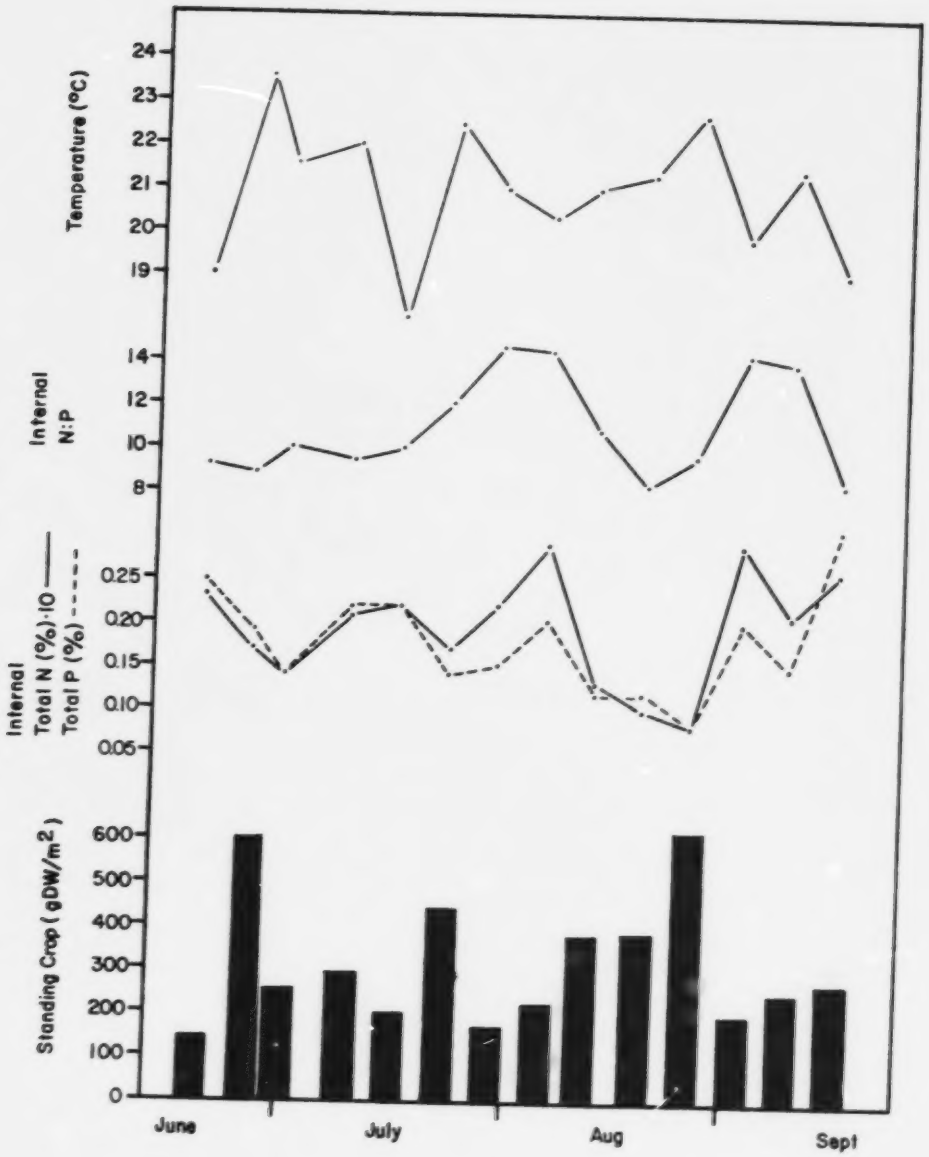


Figure 29: Cladophora standing crop, temperature and internal total phosphorus and nitrogen and N:P ratios at KI in Lake Simcoe, 1976

Table 8: Matrix of simple correlation coefficients between Cladophora standing crop at 0.5 m depth (BIO), temperature (TEMP), internal total phosphorus (CTP), nitrogen (CTN) and nitrogen to phosphorus ratio (CNP) at KI in Lake Simcoe, June 16 through September 17, 1976 (n = 14).

	TEMP	CTN	CTP	CNP
BIO	0.76**	-0.70**	-0.50	-0.39
TEMP		-0.59*	-0.63*	-0.03
CTN			0.76**	0.49
CTP				-0.18

** $P < 0.01$
* $P < 0.05$

REPT 10-B-2

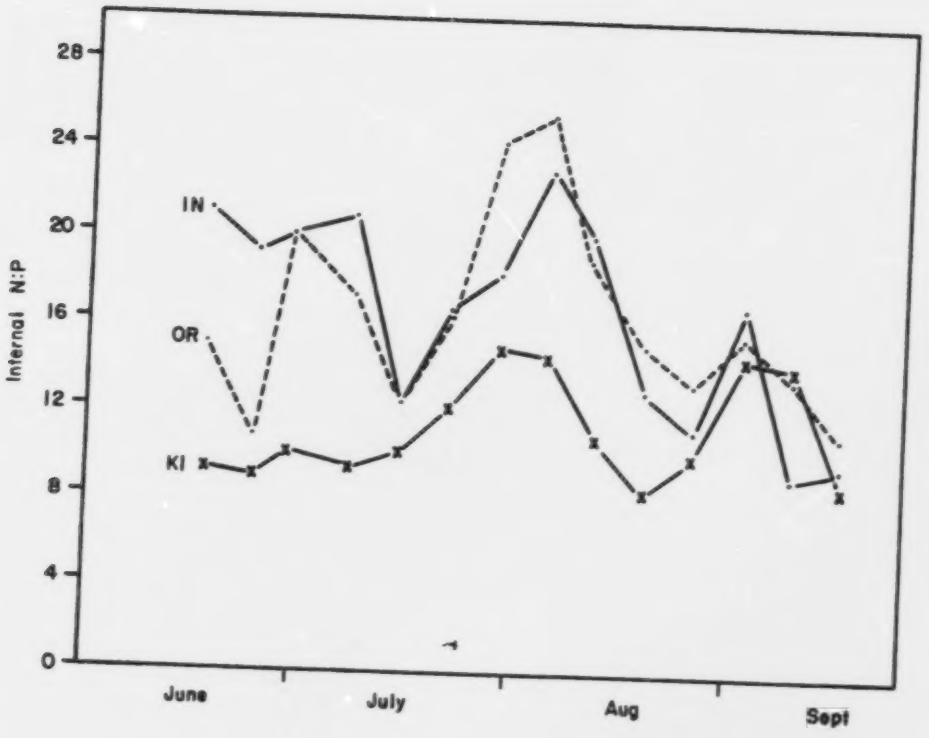


Figure 30: Internal N:P ratios at KI in Lake Simcoe, 1976

Table 9: Results of stepwise multiple regression analysis between Cladophora standing crop at 0.5 m depth and significant independent variables, temperature (TEMP) and internal nitrogen to phosphorus ratio (CNP) at KI in Lake Simcoe, June 16 through September 17, 1976 (N = 14).

Independent Variable	Multiple R	Multiple R^2	Change in Multiple R^2
TEMP	0.76	0.58	0.58**
CNP	0.84	0.71	0.13**

** F Ratio and BETA significant at $P < 0.01$

REPT 10-B-3

Table 10: Summary statistics of external concentrations of total phosphorus (Total P) soluble reactive phosphorus (SRP), total inorganic nitrogen (TIN), and total Kjeldahl nitrogen (TKN) at nearshore sites in Lake Simcoe, 1976 and 1980.

			Total P (ug/L)			SRP (ug/L)			TIN (ug/L)			TKN (ug/L)			
Year	Shore	Site	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	n
1976	West	KO	34	19	14- 89	3	4	0-19	31*	30	1- 128	550	190	290-1200	23
		IN	19	9	10- 47	2	2	0-10	14	12	0- 45	415	108	280- 700	24
		BI	16	7	5- 29	2	2	0- 8	17	21	1- 82	393	67	260- 600	25
		BD	31	26	4-124	7	10	0-40	37	53	0- 228	429	103	300- 680	22
		DE	28	24	11-110	4	5	0-20	76	127	0- 554	394°	124	300- 930	24
		OR	23	14	8- 52	1	1	0- 4	12	19	0- 94	432	114	280- 730	24
		CA	19	11	6- 52	1	1	0- 4	7	6	1- 29	416	108	290- 780	24
		CO	20	14	10- 66	1	1	0- 3	11	12	0- 51	419	99	320- 800	22
		KI	37	38	10-172	5	5	0-19	124	273	1-1125	567	323	320-1690	24
1976	East	MC	23	13	10- 52	1	1	0- 4	9	10	0- 36	415	140	290- 800	11
		LC	31	20	12- 82	1	1	0- 2	17	24	0- 73	438	104	310- 700	12
		TN	30	15	9- 56	2	1	1- 3	41	89	3- 319	444	141	200- 740	12
		BN	34	40	11- 141	2	2	1- 9	111	99	5- 255	581	165	300- 820	10
		BS	31	24	8- 87	2	1	1- 3	31	39	3- 130	434	92	320- 580	10
		PE	29	21	9- 87	1	1	0- 3	33	34	8- 130	483	117	280- 670	11
		WI	17	5	9- 26	2	1	1- 5	14	16	1- 56	383	58	300- 490	12
		RO	24	12	14- 59	2	2	0- 6	25	37	3- 134	433	115	190- 640	12
1980	W/E	GR	66	25	35- 115	7	6	0-17	96	80	17- 282	758	243	330-1200	10
		IN	19	9	8- 37	2	2	0- 6	45	23	7- 85	437	99	260- 680	12
		BI	15	5	6- 28	4	6	0-19	79	136	11- 506	380	63	220- 460	12
		BO	38	30	15- 125	7	7	0-20	168	163	32- 623	539	137	410- 850	12
		BL	24	8	14- 38	6	7	0-22	91	81	24- 250	449	91	360- 630	7
		KI	42	29	10- 122	10	9	1-35	201	276	33-1023	535	202	370-1130	12
		TC	29	9	16- 43	4	3	1-11	59	38	16- 133	464	65	320- 560	11
		PE	54	33	20- 125	4	4	0-14	80	68	29- 220	615	217	260-1100	11

+ n = 21
° n = 23

ns/REPT 10-C-2

Table 11: Summary statistics of internal total phosphorus (Total P) nitrogen (Total N) and nitrogen to phosphorus ratio (N:P) in Cladophora at nearshore sites in Lake Simcoe, 1976 and 1980.

			Total P (%)			Total N (%)			N:P			
Year	Shore	Site	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	n
1976	West	KO	0.15	0.08	0.09-0.27	2.5	0.7	1.3-4.1	16.3	2.6	11.8-21.3	20
		IN	0.16	0.08	0.08-0.45	2.0	0.4	1.3-2.9	14.5	5.2	6.4-23.0	23
		BI	0.15	0.08	0.08-0.34	2.2	0.6	1.2-3.5	17.5	7.6	5.0-31.2	22
		BD	0.20	0.06	0.08-0.33	1.9	0.5	0.9-2.5	10.8	5.6	5.6-31.2	21
		DE	0.26	0.11	0.09-0.49	2.9	0.6	1.7-4.4	12.6	4.4	6.3-23.3	21
		OR	0.13	0.52	0.07-0.26	1.6	0.4	0.9-2.6	13.9	5.0	6.5-25.7	23
		CA	0.15	0.06	0.08-0.27	2.0	0.7	1.1-2.9	14.1	2.3	10.7-18.0	7
		CO	0.13	0.04	0.06-0.19	2.2	0.6	1.2-3.0	17.9	4.2	7.5-24.4	22
		KI	0.21	0.07	0.08-0.37	2.2	0.7	0.8-3.9	10.7	2.2	8.1-14.7	24
1976	East	MC	0.12	0.06	0.08-0.23	1.8	0.3	1.4-2.2	16.6	5.1	9.6-21.2	6
		LC	0.06	0.03	0.03-0.10	1.4	0.2	1.2-1.7	27.0	8.8	16.0-40.0	7
		TN	0.10	0.03	0.07-0.14	2.0	0.3	1.6-2.4	20.4	3.6	15.7-24.3	6
		BN	0.14	0.08	0.05-0.28	2.3	0.4	1.9-3.0	20.9	10.0	8.2-38.0	6
		BS	0.10	0.01	0.09-0.12	1.8	0.2	1.6-2.0	18.6	1.7	16.7-20.0	4
		PE	0.19	0.04	0.13-0.27	2.2	0.4	1.6-2.9	12.2	3.3	7.0-16.1	9
		WI	0.10	0.02	0.06-0.12	1.9	0.6	1.1-2.9	19.9	5.6	13.8-30.0	7
		RO	0.20	0.08	0.10-0.39	2.3	0.6	1.6-3.7	12.1	3.8	7.7-21.0	10
1980	W/E	GR	0.26	0.06	0.18-0.36	3.2	0.7	2.4-4.4	11.4	4.2	10.2-15.2	8
		IN	0.17	0.07	0.09-0.29	2.8	0.8	1.7-4.5	17.2	3.1	12.4-21.8	10
		BI	0.14	0.04	0.08-0.22	2.6	0.5	2.2-3.7	22.3	7.5	13.8-36.2	8
		BO	0.27	0.12	0.11-0.46	2.6	0.8	1.5-4.0	10.4	2.0	6.8-13.6	10
		BL	0.18	0.06	0.10-0.27	2.7	0.7	1.9-3.4	16.1	2.5	12.2-20.0	6
		KI	0.28	0.18	0.07-0.65	3.0	1.8	0.8-6.1	11.5	3.0	8.6-18.9	9
		TC	0.21	0.08	0.10-0.34	3.8	1.1	0.2-4.6	18.6	3.7	14.1-25.0	10
		PE	0.19	0.06	0.12-0.27	3.0	1.0	1.9-5.2	16.2	2.4	13.1-19.3	9

ns/REPT 10-C-3

temperature and internal N:P, as determined in the stepwise multiple regression analysis ($R = 0.84$, $P < 0.01$).

$$g\ DW/m^2 = 73(°C) - 23(N:P) - 946 \quad (1)$$

Figure 30 shows that the frequency in fluctuations of internal N:P is similar at KI, OR and IN, all relatively exposed sites on the west shore of Lake Simcoe. The lower mean internal N:P ratio at KI, during June through August, reflects the overall increased availability of nutrients at this location compared to OR and IN (see Tables 10 and 11). Note that this negative relationship between internal N:P and internal nutrients, based on 'mean' levels, is the opposite of the temporal relationship described above at KI. In the later case, week-to-week growth demands cause regular fluctuations in the proportions and absolute levels of internal total phosphorus and nitrogen.

(b) Nutrients and Heavy Metals

(i) Phosphorus and Nitrogen

Tables 10 and 11 list summary statistics of external and internal total phosphorus and nitrogen levels and internal N:P ratios at nearshore sites in Lake Simcoe in 1976 and 1980. For comparative purposes, only the mean values of these parameters are illustrated in Figures 31, 32, and 33. Variability between sites suggests that external and internal nutrient levels are higher at 'affected' sites than at 'remote' sites (see Figure 28 and Table 6), and that high mean internal N:P ratios generally reflect low nutrient availability and vice versa. There is also some indication that nutrient levels in 1980 are higher than in 1976 (compare year-to-year differences at IN, B1, KI and PE).

Discriminant analysis is used to determine:

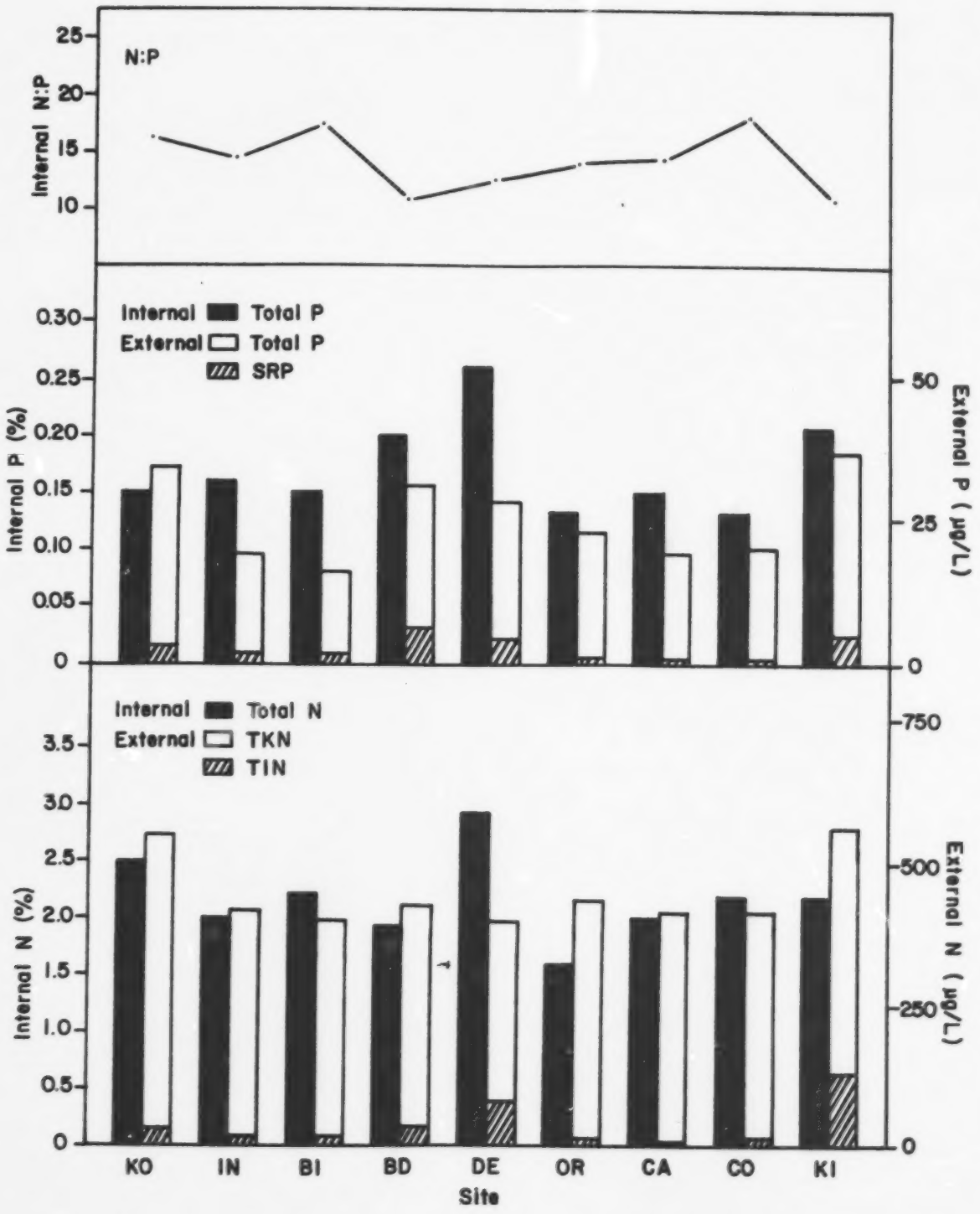


Figure 31: Mean external and internal phosphorus and nitrogen parameters at the west nearshore sites in Lake Simcoe, June through November, 1976.

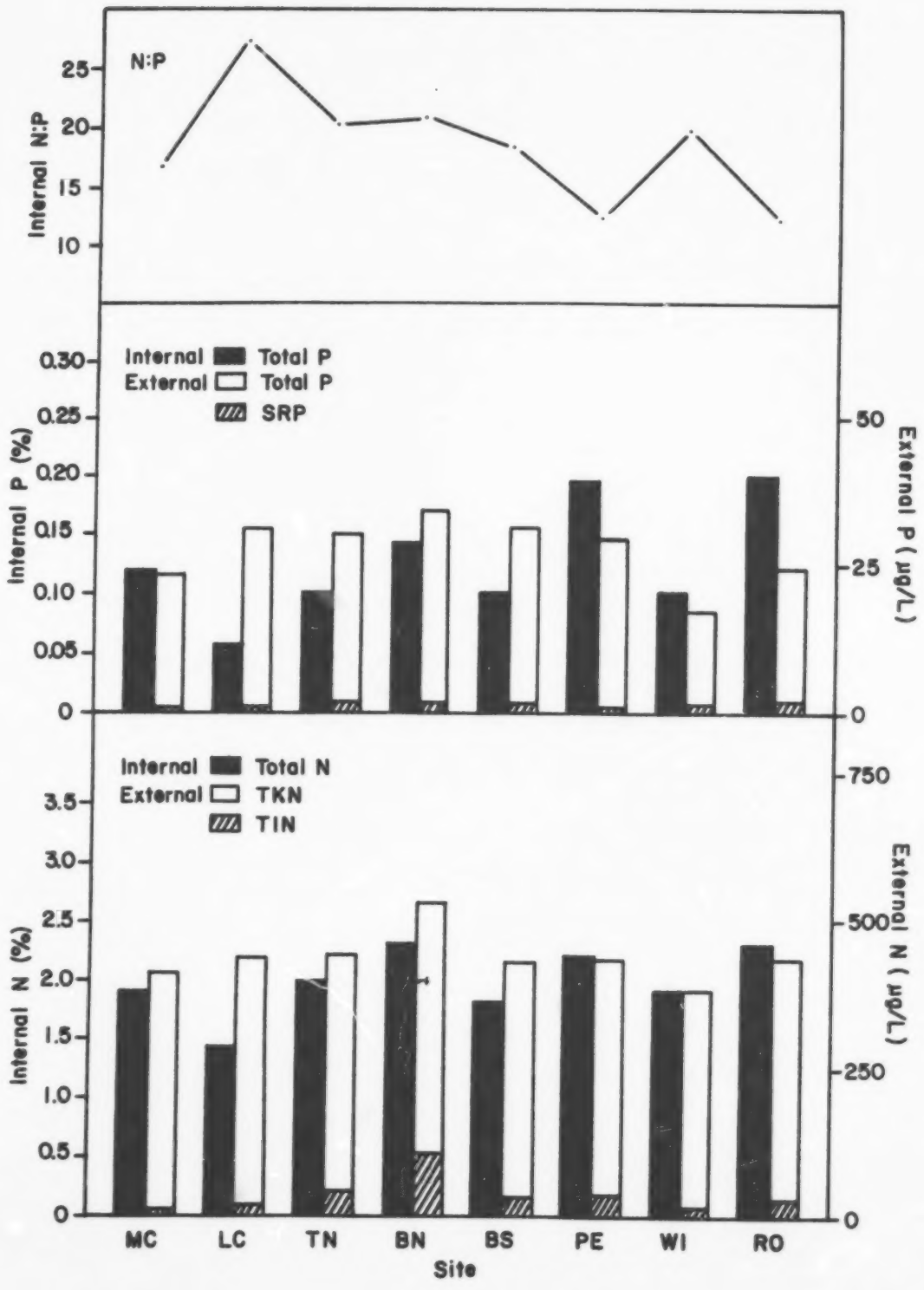


Figure 32: Mean external and internal phosphorus and nitrogen parameters at the east nearshore sites in Lake Simcoe, August through October, 1976.

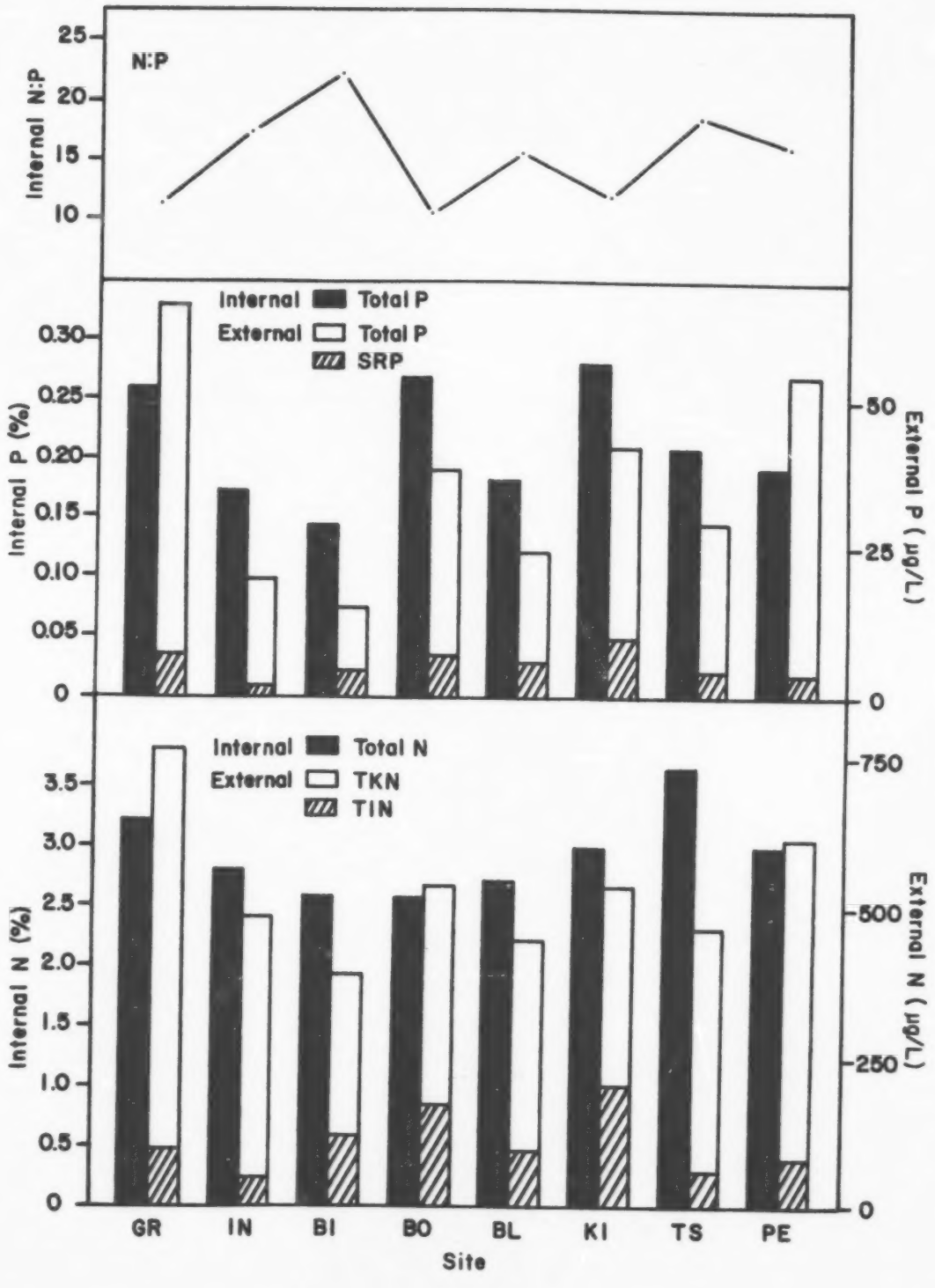


Figure 33: Mean external and internal phosphorus and nitrogen parameters in Lake Simcoe, May through October, 1980.

1) whether the 'affected' sites can be statistically distinguished from the 'remote' sites;

2) to establish what individual nutrient parameters are most important in discriminating between the two groups of sites; and

3) to assess spatial and temporal differences in nutrient availability by comparing the discriminant scores of individual sites.

The results of direct discriminant analysis in Table 12 show a high degree of separation between the 'affected' and 'remote' sites as indicated by a Wilks' Lambda of 0.47 ($P<0.05$) and a canonical correlation of 0.73 for the first, and only, discriminant function. The standardized canonical discriminant function coefficients listed in Table 13 represent the relative contribution of each nutrient variable to the discriminant function. Because of the relatively high contributions of external total phosphorus, internal total phosphorus and internal N:P, the discriminant function is predominantly a continuum of these three nutrient parameters.

The discriminant scores of all of the nearshore sites sampled in 1976 and 1980 are compared in Figure 34. Each of the 'remote' sites is classified correctly, while two of the 'affected' sites, RO (1976) and TN (1976), fall just within the upper limit of the 'remote' category. The mean discriminant scores of the 'affected' and 'remote' sites are 0.8 and -1.3. Of the four sites frequented in both years, the discriminant scores are higher in 1980 than in 1976. Of these sites, the two 'affected' locations, KI and PE, show increases of 1.1 and 2.3 in their discriminant scores from 1976 to 1980. The scores of the two 'remote' sites, B1 and IN, are 0.7 and 0.5 higher in 1980 than 1976.

Table 12: Results of direct discriminant analysis between 'affected' and 'remote' sites in Lake Simcoe, 1976 and 1980. The discriminating variables are internal total phosphorus (CTP), nitrogen (CTN) and phosphorus to nitrogen ratio (CNP) and external total phosphorus (TP), soluble reactive phosphorus (SRP), total inorganic nitrogen (TIN) and total Kjeldahl nitrogen (TKN). R = discriminant function canonical correlation; SC = standardized canonical discriminant function coeffient.

R	R^2	Wilks' Lambda
0.73	0.53	0.47*
Variable	SC	
TP	−0.97	
CNP	−0.97	
CTP	0.95	
CTN	−0.69	
TIN	0.55	
TKN	0.49	
SRP	0.06	

* $P < 0.05$

REPT 10-B-4

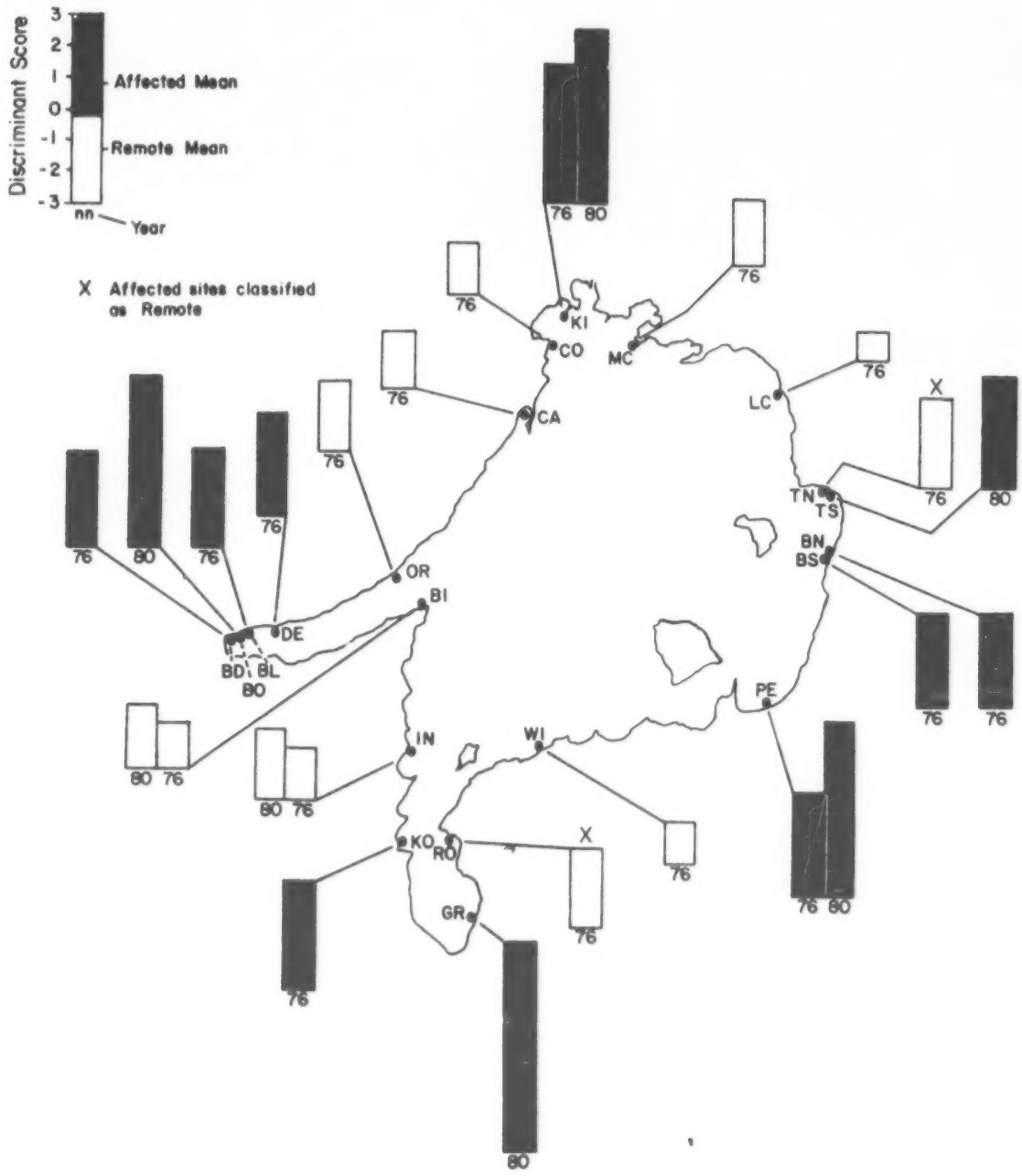


Figure 34: Discriminant scores of 'affected' and 'remote' nearshore sites in Lake Simcoe, 1976 and 1980. For ease of interpretation, the signs of the discrimnant scores have been reversed from the original computer printout so that increasing scores reflect increasing 'nutrient status'.

Table 13: Summary statistics of internal total mercury (Total Hg) and lead (Total Pb) in Cladophora at nearshore sites in Lake Simcoe, 1980.

	Total Hg (µg/g)			Total Pb (µg/g)			
Site	X	SD	Range	X	SD	Range	n
GR	0.02	0.02	<0.01-0.06	8	3	5- 12	7
IN	0.02	0.04	<0.01-0.12	14	7	2- 22	11
BI	0.02	0.03	<0.01-0.08	11	2	8- 15	10
BO	0.03	0.02	<0.01-0.08	199	84	100-338	9
BL	<0.01	0.01	<0.01-0.03	36	10	25- 48	6
KI	<0.01	<0.01	<0.02-0.01	8	4	6- 18	10
TS	0.01	0.02	<0.01-0.05	7	6	2- 21	9
PE	0.01	0.02	<0.01-0.05	9	7	2- 25	9

REPT 10-B-5

The highest discriminant score is 3.3 at GR (1980) and the lowest is -2.1 at LC (1976). PE (1980), K1 (1981), BO (1980 and KI (1976) are all grouped with GR (1980) in the upper level of the 'affected' category, while WI (1976) and BI (1976) are grouped with LC (1976) in the lower level of the 'remote' category. In general, the remaining sites are clustered, in their appropriate categories, about the borderline score.

(ii) Mercury and Lead

Table 13 lists summary statistics of Cladophora internal total mercury and total lead levels at nearshore sites in Lake Simcoe in 1980. The mean values of these parameters are compared in Figure 35. Mean internal total mercury concentrations range from nondetectable ($<$ 0.01 ug/g) at BL and KI to 0.03 ug/g at BO. The remaining sites have mean mercury levels of either 0.01 ug/g or 0.02 ug/g. The highest mean internal total lead concentrations are 36 ug/g and 199 ug/g at BL and BO, while the lowest mean value is 7 ug/g at TS. The remaining sites have mean lead levels of between 8 ug/g and 14 ug/g.

3.5 DISCUSSION

The exessive growth of Cladophora at KI is highly visible evidence of nearshore nutrient enrichment. Although other locations in Lake Simcoe are similarly impacted in terms of nutrient availability (see Tables 7, 10 and 11), in every case, physical factors limit the extent of Cladophora growth.

The maximum depth distribution of Cladophora at KI is about 3 m, while most of the biomass production is limited to the 0.5 m depth zone. Cladophora grows to depths of 5-10 m at nearshore sites in Lakes Erie and Ontario where water clarity and nutrient levels are no more favourable than at KI (Neil and Jackson 1982, Shear and Konasewich 1975).

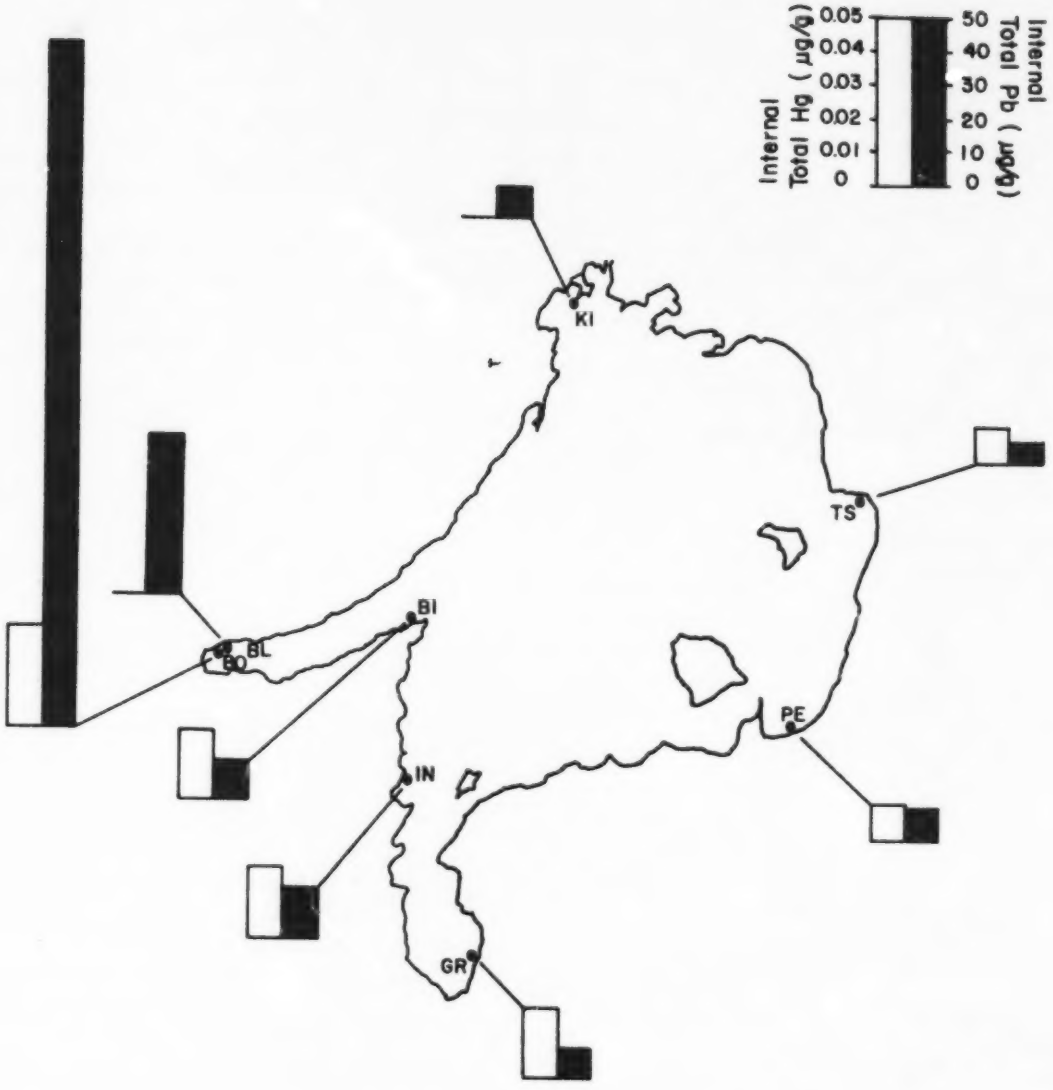


Figure 35: Mean internal total mercury and lead concentrations at nearshore sites in Lake Simcoe, 1980.

It follows that the smaller fetches in Lake Simcoe probably result in less than optimal nearshore turbulence for the efficient maintenance of nutrient uptake kinetics in Cladophora (Whitton 1970). This stress, in turn, would alter the efficiency of light utilization, thus, limiting the maximum depth occurrence of the alga.

Temperature and prevailing weather conditions greatly affect the periodicity of Cladophora growth at KI in Lake Simcoe. In 1976, each of the peak biomass events coincided with attainment of maximum water temperatures of between 22.5°C to 23.5°C. The first event followed the initial rapid increase in temperature during June, while the second and third events followed periods of reduced temperatures of below 21°C in July and August. After each event, the accumulated biomass was sloughed and driven ashore by wave action.

Investigations of Cladophora growth in Lake Erie typically show a 'single' temperature-dependent growth phase cumulating in peak standing crop at temperatures of 18°C to 25°C in late June or early July. Following wind-induced sloughing, maintenance of summer temperatures above 21°C inhibits any further growth until fall when reduced temperatures may stimulate a limited growth resurgence (Lorenz and Herdendorf 1982, Millner et al 1982, Neil and Jackson 1982, Taft and Kishler 1973).

A comparable data set showing multiple peak biomass events is from Harbour Beach in Lake Huron, where four events were recorded during June through September (Auer et al. 1980). For the first three events, the relationship between temperature, standing crop and wind-induced sloughling is highly consistent with that described above at KI. The fourth event occurred in September at 18°C following a reduction in temperature to 15°C. This is consistent with observations in Georgian Bay and Lake Ontario (O.M.E. unpublished data) which indicate that the 'optimal' temperature for growth is in the 15°C range.

Thus, there is good evidence to show that in the Great Lakes, including Lake Simcoe, Cladophora exhibits a temperature-dependent growth

phase only if increasing temperatures are initiated from below 21°C. Maintenance of mid-summer temperatures above this level inhibitis growth, while the optimum temperature for growth is about 15°C.

The overwhelming importance of temperature in controlling the periodicity of Cladophora growth at KI, in Lake Simcoe, is substantiated in the strength of the statistical relationships presented here. In stepwise multiple regression analysis, 58% of the week-to-week variability of Cladophora standing crop is explained by temperature. Importantly, an additional 13% of the variability is explained by internal N:P, indicative of the effect of internal nutrient supply.

The information presented in Figure 29 and Tables 8 and 9 suggest the following causative relationships between temperature, wind-induced sloughing, internal nutrients and Cladophora growth. Increasing temperatures (from below 21°C) stimulate rapid growth causing depletion of internal nutrient levels; nitrogen being depleted faster than phosphorus resulting in lower N:P ratios. Reductions in temperature (to below 21°C), following each sloughing event, reduce growth enabling internal nutrient levels to increase; nitrogen being taken up faster than phosphorus resulting in higher N:P ratios. The similarity in the frequency of week-to-week fluctuations of internal N:P at KI, OR and IN (Figure 30) indicates that the above causative relationships may have general application, at least to physically similar locations, in Lake Simcoe.

Cladophora growth at KI may be frequently nitrogen limited since internal total nitrogen is significantly correlated with standing crop ($R = -0.70$, $P < 0.01$) while internal total phosphorus is not ($R = -0.50$, $P > 0.05$). In addition, the 'mean' internal N:P ratio at KI (10.7) approximates Sakamoto's (1966) criteria for nitrogen limitation of $N:P < 10$. The relatively low mean internal N:P ratio at KI reflects the higher availability of nutrients (i.e. phosphorus) and greater Cladophora growth potential at this location compared to OR and IN.

A comparision of all the nearshore sites in Lake Simcoe, in 1976 and 1980, shows measurable differences in local nearshore nutrient status. Through the use of discriminant analysis, a number of internal and external phosphorus and nitrogen parameters (Figures 31, 32 and 33) are reduced to a 'single' discriminant function on which all of the 'remote' sites and 'affected' sites are compared (Figure 34). The discriminant function is primarily a continuum of external total phosphorus, internal total phosphorus and internal N:P. Site-to-site differences in discriminant scores show that major inflows (GR, KO, PE, BN, BS) and urban-industrial areas (BD, BO, BL, DE, KI), markedly elevate nearshore nutrient status relative to remote locations. Year-to-year differences in nutrient status are also apparent in that all of the sites sampled in both years (KI, PE, IN, BI) show higher discriminant scores in 1980 than 1976. However, it is impossible to determine the importance of these time differences since year-to-year variability attributable to environmental factors is unknown.

Site-to-site differences in internal levels of total mercury and total lead in Lake Simcoe, in 1980, also show apparent local effects (Figure 35). These metals are of particular concern because of their capacities to undergo methylation to more toxic forms and bioaccumulate in aquatic organisms (I.J.C. 1980). Mean internal total mercury concentrations are measurable at six of the eight nearshore sites in 1980. Although values are either at or close to the limit of detection (0.01 µg/g), there is some indication that mercury levels are highest in Cook Bay (GR, IN) and Kempenfelt Bay (BI, BO). In general, internal total mercury concentrations in Lake Simcoe are comparable to levels in Lake Ontario near Toronto (O.M.E. unpublished data).

Mean internal total lead concentrations are measurable at all eight of the 1980 sampling sites at concentrations three orders of magnitude greater than mercury. Lead levels average about 10 µg/g at most sites except near Barrie where concentrations range from 36-199 µg/g (BO, BL). As with mercury, these internal lead values are comparable to similarly impacted nearshore areas in Lake Ontario (O.M.E. unpublished data).

3.6 SUMMARY

1. Insufficient nearshore water turbulence appears to be the primary physical factor limiting the growth of Cladophora in Lake Simcoe.

2. The excessive proliferation of Cladophora at KI, an exposed cobblestone beach just east of the Orillia Sewage Treatment Plant outfall, is highly visible evidence of nearshore nutrient enrichment.

3. The periodicity of Cladophora standing crop at KI is largely influenced by temperature and prevailing weather conditions, while the supply of internal nutrients (as indicated by the internal N:P ratio) is of secondary, but measurable importance.

4. Cladophora growth at KI appears to be frequently nitrogen limited because of the relatively high availability of phosphorus.

5. In Lake Simcoe and in the Great Lakes, Cladophora exhibits a temperature-dependent growth phase only if increasing temperatures are initiated from below 21°C. Maintenance of mid-summer temperatures above this level inhibits growth, while the optimum temperature for grothw is in the 15°C range.

6. Results of discriminant analysis show that 'affected' sites impacted by major inflows and nutrient status (i.e. higher discriminant scores) than 'remote' sites in Lake Simcoe.

7. Discriminant scores are higher in 1980 than 1976; however, it is impossible to determine the importance of these time differences since year-to-year variability attributable to environmental factors is unknown.

8. Mean internal total mercury and total lead concentrations at the eight sites sampled in 1980 are comparable to values in Lake Ontario near Toronto. Internal total mercury concentrations appear to be higher in Cook Bay and Kempenfelt Bay and internal total lead concentrations are especially high near Barrie.

3.7 ACKNOWLEDGEMENTS

The contributions of the following staff of the Water Resources Branch, Ontario Ministry of the Environment are acknowledged: Malcomb Winter, Derek Connelly, Glenn Robinson and Chuck Cox for field assistance, Liza Vandermeer for data preparation and Ken Nicholls for review of the manuscript. Thanks are also due to the personnel of the Inorganic Trace Contaminants Section and the Water Quality Section, Laboratory Services Branch for analytical support.

REFERENCES

Auer, M.T., and Canale, R.P. 1980. Phosphorus uptake dynamics as related to mathematical modelling of Cladophora at a site on Lake Huron. J. Great Lakes Res. 6(1):1-7.

Auer, M.T., Canale, R.P., Matsuoka, Y., and Grundler, H.C. 1980. Modeling the response of the nuisance alga, Cladophora glomerta, to reductions in phosphorus loadings. Pages 47-52 in Int. Symp. Inland Waters and Lake Restoration, Sept. 8-12, 1980, Portland, Maine, E.P.A., Washington, D.S.

Herbst, R.P., 1969. Ecological factors and the distribution of Cladophora glomerata in the Great Lakes. Am. Mid. Nat. 82:90-98.

International Joint Commission, 1980. Pollution in the Great Lakes basin from land use activities. Int. Joint Comm., Windsor, Ontario. P. 141.

Jackson, M.B. and Hamdy, Y.S. 1982. Projected Cladophora growth in southern Georgian Bay in response to proposed municipal sewage treatment plant discharges to the Mary Ward Shoals. J. Great Lakes Res. In Press.

Keeney, W.L. 1976. The determination of trace metals in Cladophora gomerata - C. gomerata as a potential biological monitor. Water Research 10:981-984.

Lin, C.K. 1971. Availability of phosphorus for Cladophora growth in Lake Michigan. Pages 39-43 in 14th Conf. Great Lakes Res. Int. Associ. Great Lakes Res.

Lorenz, R.C. and Herdendorf, C.E. 1982. Growth dynamics of Cladophora glomerata in western Lake Erie in relation to some environmental factors. J. Great Lakes Res. In Press.

Millner, E.C., Sweeney, R.A., and Frederick, V.R. 1982. Biomass distribution of Cladophora gomerata and their relationship to some physical-chemical variables. J. Great Lakes Res. In Press.

Neil, J.H. and Jackson, M.B. 1982. Monitoring Cladophora growth conditions and the effect of phosphorus additions at a shoreline site in northeastern Lake Erie. J. Great Lakes Res. In Press.

Neil, J.H. and Owen, G.E. 1064. Distribution, environmental requirements and significance of Cladophora in the Great lakes.

Pages 113-121 in Proc. Seventh Conf. Great Lakes Res. Publ. 11. Great Lakes Res. Div. Univ. of Mich., Ann Arbor, Mich.

Niel, N.H., Hull, C.H., Jenkins, J.G. Steinbrenner, K., and Bent, D.H. 1975. Statistical package for the social sciences. 2nd ed. McGraw-Hill, New York, p. 675.

Ontario Ministry of the Environment. 1981. Outlines of analytical methods: A guide to the occurrence, significance, sampling and analysis of chemical and microbiological parameters in water, sediment, soil, vegetation and air. Coordinated by the Water Quality Section, Laboratory Services Branch, Toronto, Ontario. p. 246.

Shaw, H., and Konasewich, D.E. 1975. Cladophora in the Great Lakes. Int. Joint Comm., Windsor, Ontario.

Taft, C.E., and Kischler, W.J. 1973. Cladophora as related to pollution and eutrophication in western Lake Erie. Water Resources Centre, Ohio State University, Columbus, Ohio.

Whitton, B.A. 1970. Biology of Cladophora in freshwaters. Water Res. 4:457-476.

ns/REPT 10-A